ETI
ELECTRONICS
TODAY INTERNATIONAL

6 MOD 55 60 73
19 64
26 69
42 72
49 CAT

SUN, SEA AND BATTERIES ON THE GLOBAL GREEN CAT

Sailing round the globe on solar power

COMPUTER AIDED DESIGN ON A SHOESTRING

Spreadsheet Circuit Simulation

PIC-CONTROLLED MIDI PROCESSOR

Process And Re-send MIDI Signals
With Easy PIC Effects Software

CIRCUITS FOR MUSIC LOVERS

Vocal Presence, Ricky Sound
And Two Waa-Waa circuits

FOR ENTHUSIASTS BY ENTHUSIASTS
NEXUS
Vol. 27 Issue: 11 Price £2.75
9th October 1998 - 5th November 1998

PLUS

- LOOP ALARM
- VERSATILE DIODE
- PC-CONTROLLED DOT MATRIX DISPLAY

Electronics and Computing • Projects for the Future

Contents

Volume 27
No.11

Next Issue
6th November 1998

& Features Projects

Power Management for the Global Green Cat 10

Planned as the First Solar Circumnavigator, the Global Green Catamaran is designed to circumnavigate the globe in a (45ft) catamaran powered only by the output of photovoltaic solar panels and with one woman at the helm. Tony Howarth describes how the Cat will "keep going" without sails even on a cloudy day.

PIC-Controlled MIDI Processor 19

Robert Penfold's MIDI processor takes a MIDI signal, processes it in one of a variety of ways, and re-sends it under PIC control. The receiver is sent the input signal via a fast opto-isolator that provides a UART with logic-level signal. Sample software is included.

Circuits for Music Lovers (Part 1) 26

Some circuit ideas including vocal presence and guitar Waa-waa, with a Byrd's-style "Ricky Sound" effect to build. By James Scott.

Professional PC-Controllable 4-Line Dot Matrix Display (Part 2) 34

The second of three articles describing Robert Coward's modular display system with four multicoloured 24-character display lines and a display management board. This month: choosing suitable power supplies, and making any changes required to the display panels and control board.

Getting MORE out of PICs (Part 6): Arithmetic Routines 42

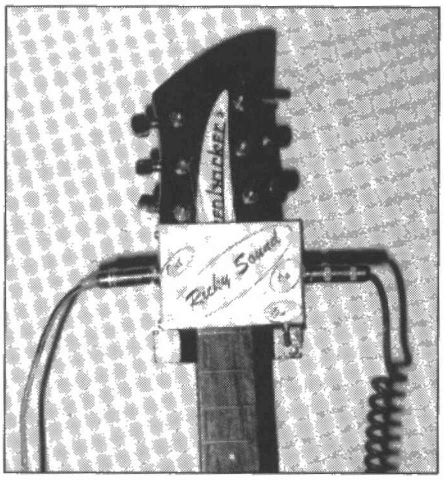
In the last part of this series on advanced PIC programming, Robin Abbott looks at a number of routines for arithmetic on 32 bit numbers.

The Versatile Diode 49

Diodes do other things besides rectifying. Keith Garwell has designed a temperature probe and two mains control applications for diode circuits.

Timing in Electronics (Part 5): Starting and Stopping 55

This month Owen Bishop covers timer gating circuits to start and stop the clock. This includes a design for a reaction timer with an accuracy of 1/100 second.

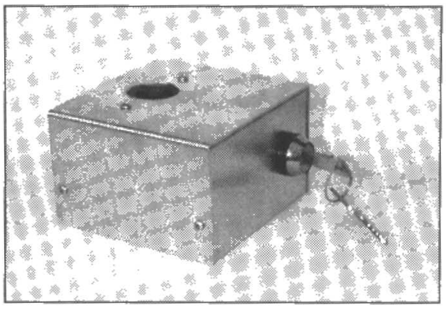


Computer Aided Design on a Shoestring 60

John Howden has developed a method of using an everyday spreadsheet to simulate component interactions in a circuit design, applying the spreadsheet's ability to do instant calculations.

International Model Show 65

The International Model Show and The Model Engineer Exhibition will be held at the Grand Hall, Olympia, from 29th December to 3rd January 1999.



Versatile Loop Alarm 66

Terry Balbirnie's alarm was originally designed for his caravan, but can be used for any number of articles that can be "looped" with the alarm wire that detects a broken circuit.

Regulars

News 4,5,6,7

ETI PCB Service 64

PCB foils 69

Practically Speaking 73

Terry Balbirnie describes to achieve a required value for a variable resistor by using one of a higher value.

Round the Corner 74

☎
SUBSCRIPTIONS
& BACK ISSUES HOTLINES:
01858 435344
ORDERS:
ENQUIRES:
01858 435322
Lines Open 9am - 6.30pm

Subscribe & Save

Phone the hotline and take advantage of our special offer detailed on page 33.

ETI
ELECTRONICS
TODAY INTERNATIONAL

News...

Biometric Conference In London

Still backing the hunch that in the future human data will be implanted in machines, rather than machines implanted in humans, the biometrics industry (See *The Eye That Never Sleeps*, ETI Issue 8 1998, and *The Finger Than No-one Forgets*, ETI Issue 9 1998) is holding the first UK conference to focus on the practical applications of biometrics on a global basis. The conference, Biometrics '98, is organised by the industry newsletter *Biometric Technology Today* and will take place at the London Heathrow Hilton Hotel on 17th, 18th and 19th November 1998.

For more information, contact Vicky Morland, SJB Services, tel 01458 253344 Fax 01458 243366 email vmorland@sjb.co.uk, or access the Conference website a www.sjb.co.uk/bio98.

biometrics 98
EXHIBITION AND CONFERENCE

Cybernetics Professor Becomes Cybernetic Man With Transponder Implant

Professor Kevin Warwick, Professor of Cybernetics at the University of Reading, has furthered the cause of research into human/machine interaction by having an electronic transponder implanted in his forearm under local anaesthetic.

The transponder, around 23mm long and 3mm in diameter, is a commercial unit made up of a glass capsule containing a coil of fine copper wire and a number of chips. When the transponder encounters an appropriate RF signal, current generated in the coil powers the circuitry, which transmits a unique 64-bit data signal. This is designed to be received by a receiver connected to an 'Intelligent Building' network. A computer on the network recognises the individual code (and the human attached to it) and responds according to the pre-programmed instructions associated with that code.

The computer can operate devices such as doors, lights, heaters or other computers, depending on how the individuals transmitting the signals have set up their requirements in the system (or had them set up for them).

So, the tea machine would always serve you with exactly the right amount of sugar, whitener and artificial tea substitute, your room and desk lights, fan/heater and soldering/extraction station would switch on at precisely the right setting each time you returned to your desk, your personal computer folder would boot up at any workstation where your presence was detected, and the nearest telephone extension would automatically pick up your calls and direct them to you.

On a more personal level, the implant could replace your Access, Visa or Bankers cards, supermarket loyalty cards, petrol points account cards, library cards and electronic point of entry keys, to name but a few. The implant could carry data such as your National Insurance number, medical number and blood group, and update the data automatically where necessary. It could contain information on your medical problems, qualifications, prior convictions and even speeding fines. There is comparatively little danger of losing an implant or having it stolen. Security in banking would therefore be higher, and it would be difficult to falsify records.

On the other hand, are we facing a future of muggers armed with knockout gas and surgical scalpels instead of blunt instruments and knives?

Prof. Warwick's transponder is being tested *in situ* in Reading University, where the departmental intranet has been configured to respond to the transponder's presence in a number of ways. His personal staff are pleased with the results. His secretary, Mrs. Liz Lucas, told the university website: "It was often very hard to find Professor Warwick when he had a telephone call or a meeting, but since the implant we always know where he is."

Kevin Warwick is clearly taking a personal risk in having a glass capsule implanted in his arm, quite apart from the stresses imposed by living so intimately with a building control system. He reports: "As I walk around the building, lights go on and computers burst into life every time I scratch my head. It can be quite scary."

Does this innocent statement conceal an unreported on/off switch implanted in the professor's scalp, for use when the flow of machine interactions becomes overwhelming?

This is the future: until now, only straying pets, the occasional wrongdoer and a few government employees have been electronically "tagged". Soon, it could be everybody. Prof. Warwick is both a prophet of technological doom and and also, having brought in over £2 million in new research contracts to the University over the last two years, an agent of its steady advance.

Perhaps, after these personal experiences, he will be able to tell us what to do about it!

ETI
ELECTRONICS
TODAY INTERNATIONAL

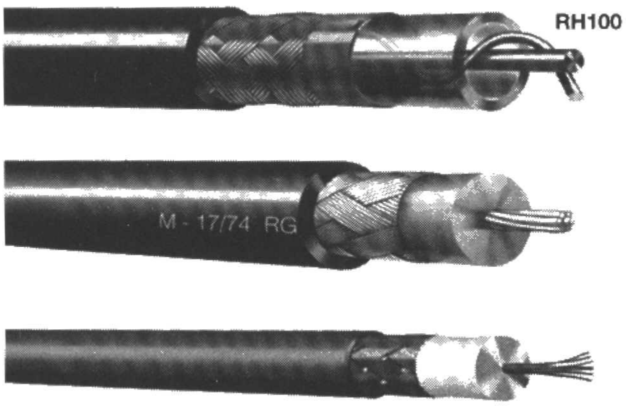
News...

Low-Loss Co-ax Cables At A Good Price

Well-known Radio and RF dealers Nevada are now distributing a new range of low-loss co-ax cables from Italian cable manufacturer Siva.

One of the range is the economical very low loss 9.77mm-diameter semi-airspaced double screened RH100. The RH100 cable gives a screening efficiency of greater than 80 percent and is suitable for frequencies up to 1GHz. It can be used with standard connectors, and costs 80p a metre +VAT. The specification of this low-loss cable gives losses per 10 metres as .35dB at 100MHz, .83dB at 400MHz and 1.22 dB at 860MHz, with velocity rating 84 percent.

For more details about the RH100 and the full range of Siva cables, contact Nevada at 189 London Road, North End, Portsmouth, Hants PO2 9AE. Tel 01705 698113 Fax 01705 690626.



Great Northern Hamfest in Barnsley, November 1st

The Great Northern Hamfest takes place on Sunday November 1st at the Metrodome Leisure Complex, Queen's Road, Bansley, S. Yorks. The Metrodome is a few minute's walk from Barnsley bus and train stations and less than two miles from M1 junction 37. Follow the brown Metrodome signs.

Doors open at 10 am. The venue is all on one level with excellent disabled facilities and plenty of free parking. There will be the usual trade stands, special interest groups, repeater groups and bring and buy. The RSGB will be there with Morse testing on demand from noon until 3pm. Talk-in will be on 145.550.

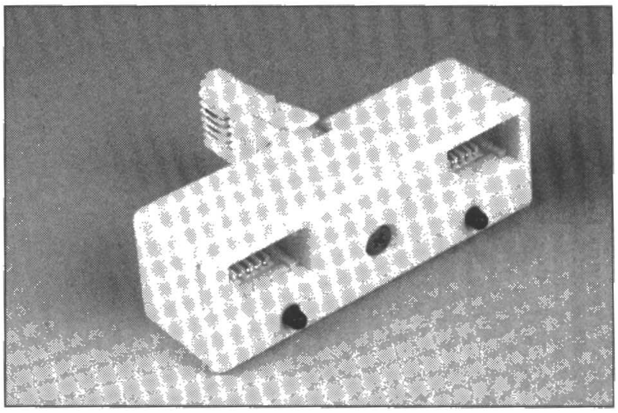
For further details contact Ernie G4LUE Tel 01226 716339 Mobile 0836 748958 from early evenings 6pm to 8pm.

AMD Fastest 1.8-Volt Flash Memory Device To Date

AMD has announced a new unit in its 1.8-volt flash memory family. The Am29SL800C 8MB device has read access times of 100 ns, making it industry's fastest 1.8V flash memory device to date.

The chip is announced as two to three times faster than competitive 1.8V devices with a speed comparable to most 3V devices. Projected applications are digital cellular handsets and other handheld applications such as pagers, personal information devices and GPS (global positioning systems). The family comes in a 1.8-volt-only version for read, program and erase, which reduces costs by removing the need for extra power supplies, and a 1.8V to 2.2V operating range version allowing longer battery cycles in a wide range of industrial applications.

For more information contact AMD UK Tel 01276 803100 Fax 01276 803102 Web http://www.amd.com



Maplin Mitigates Modem Muggings

Internet users: how many times have you been in the middle of a "surf" when your tenuous contact with cyberspace has crashed because somebody else in your home/office dialled out from another extension? Or, worse, cut in on the modem from another Internet connection or a fax machine, causing both to disconnect.

Maplin Electronics have an answer in the form of a "privacy adaptor" which allows two devices, such as a fax, phone or modem, to share a single line. As soon as one outlet is in use, the other is automatically shut off, preventing interruption and disconnection (and even eavesdropping). The adaptor is very similar to an ordinary double socket adaptor, and has LED indicators to show which socket it in use. The adaptor is self-contained and needs no batteries. The retail price if £8.509 ex-VAT one-off (£9.99 inc VAT), £7.651 ex VAT per unit 5+-off, etc.

Contact Maplin's mail order line on 01702 544000 or one of their 48 stores nationwide quoting order code NL66W.

New User-Friendly 20MHz Oscilloscope At A Reasonable Price

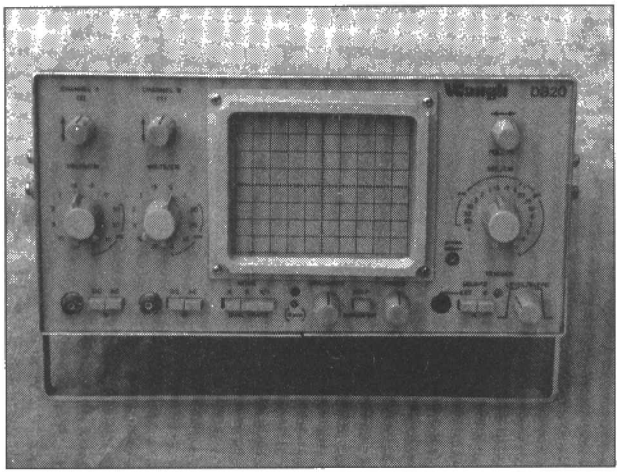
Waugh Instruments of Glyn Ceiriog have produced a new low cost 20MHz oscilloscope "with all the common pitfalls designed out", according to proprietor Peter Waugh.

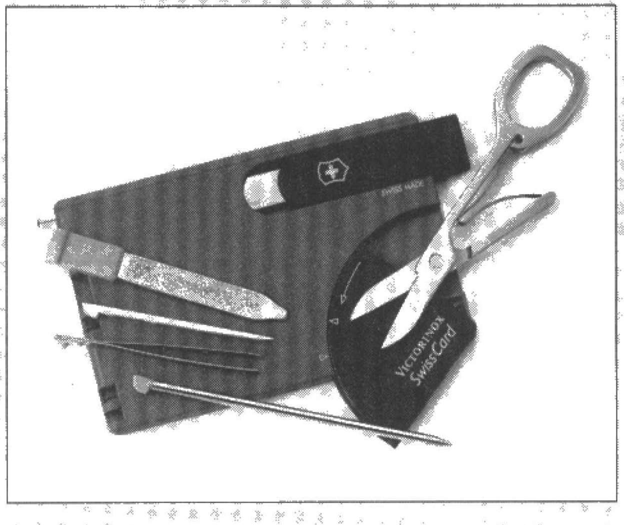
The scope boasts HELP button which restores all traces to the display screen, a flashing warning light that operates when the trigger source is not the channel being displayed and a single button on the front panel for selecting the different operating modes. The level/slope function switch is graphically marked on the front panel to show its function (bottom right in the photo).

The A & B channels have sensitivity of 5mV/div to 10V/div and accuracy of +/- 3 percent. The DC coupled bandwidth is 20MHz and the AC coupled bandwidth is 3Hz to 20MHz. Input impedance is 1Mohm +/-2 percent 30pF approx. Risetime is 18 nanoseconds. Internal trigger sensitivity gives 3mm of trace from 3Hz to 10MHz. External trigger sensitivity is 300mV over the same range.

The scope is advertised as using common and well-tried components to provide an extremely reliable instrument at a price competitive far Eastern imports. Power requirements are 220-250 VAC. The scope will operate from a 12-volt battery.

The Waugh DB20 currently costs £318. For more information, contact Waugh Instruments Ltd., Glyn Ceiriog, North Wales LL20 7PB. Tel/fax 01691 718597





Swiss Victorinox goes into wallets

The makers of the Original Swiss Army Knife, Victorinox, are entering the plastic-packed world of wallet-sized accessories with the Swiss Card, a wafer-thin credit-card-sized toolkit that won't pull your pockets out of shape.

The card is more of a laptop than a toolkit accessory, but it contains various useful items, including spring scissors, tweezers, a flat-blade screwdriver incorporated into a nail file, a mini-ruler, a miniature ballpoint pen, toothpick, pin and letter-opener quality blade with a short handle.

Unfortunately, handy items which are absent are a really sharp cutting blade or clippers, which would have upped its usefulness around the workshop. But penknife-quality scissors are a good emergency substitute, and the Card would clearly be useful to anyone with the habit of trying to use a thumbnail as a substitute screwdriver, or dropping small items into computer keyboards. And it fits into purses, handbags and wallets with ease. When your dearest says "Have you got a screwdriver on you?", you can come right back with "What about that one I gave you for Christmas, then?"

The Victorinox Swiss Card will be available from some retail stockists, or in bulk quantities as a branded business gift.

For prices and information, contact Burton McCall (distributors) on 0116 234 0800.

MODMODMODMODMODMOD

Issue 7 1998

⊗ **In Timing In Electronics Part 2:** in Figure 13, page 61, IC2 pin 14 should be connected to the +9 V strip, and the wire link from pin 12 of IC2 should go to pin 9, not to pin 8. Apologies from author and editors.

Issue 10 1998

In the Professional PC-Controllable 4-Line Dot Matrix Display (Part 1) last month, we have some small errors reported. Most important, in Figure 1, page 42, the QUICC-10M circuit diagram, resistor R18 (330R)should be shown on the line between pin 2 of PL10 (bottom centre) and LED4. The Reset switch SW2 (botton left hand corner) should go to ground between the switch and PL4 pin 2. These are shown correctly on the overlay in figure 2. In figure 2, page 44, Pin 1 of connectors PL2, PL3 and J1-4 should be marked on the left hand end in each case. In the case of J104, pin 1 goes to the anodes of the LEDs connected. Also in figure 2, the annotations intended for PL4 have migrated in order but in error to the adjacent IC4. The caption says IDM instead of 10M (and has sprouted a clone under the photo of the display on page 41) but is otherwise correct.

These have also been included at the end of this month's instalment.

NOTE ADDED TO ETI SEPT VOL 27 NO 7 1998
P 61

ETI ELECTRONICS TODAY INTERNATIONAL

News...

Very Lightweight Compact Power Supplies with Safety Approval

Artesyn Technologies have introduced a series of external power supplies for desktop and mobile applications such as network adapters, xDSL modems, cable modems, liquid crystal displays and external storage devices. The SSL20 series is a 15- to 20W universal input AC/DC external Class II 4.5 ounce (120g) power supply in a compact 107 x 57 x 25 mm plastic enclosure, with a choice of four single output versions and two multiple-output versions.

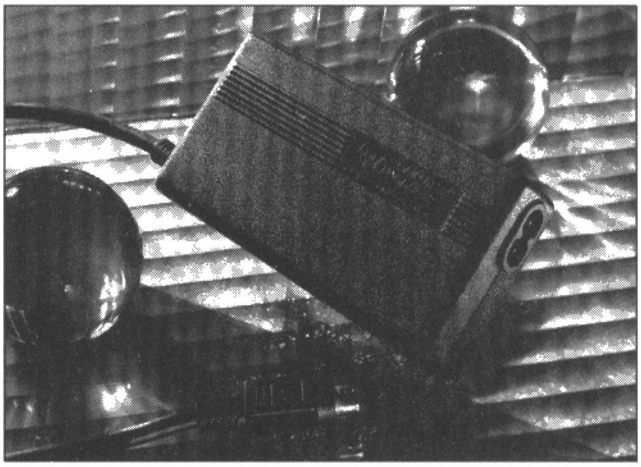
The single-output converters provide total line and load regulation with within +/-0.2 percent. The dual and triple output versions provide total regulation output of +/-0.5 percent on the auxiliary outputs. Over-voltage and short circuit protection are standard features on all models.

Meeting EN55022, EN55011 and FCC conducted and radiated emission level b, it is pre-approved for a wide variety of domestic and residential applications. The series provides

Pre-approved Safety Extra Low Voltage (SELV) outputs without the need for further safety approval or mechanical integration into the application system.

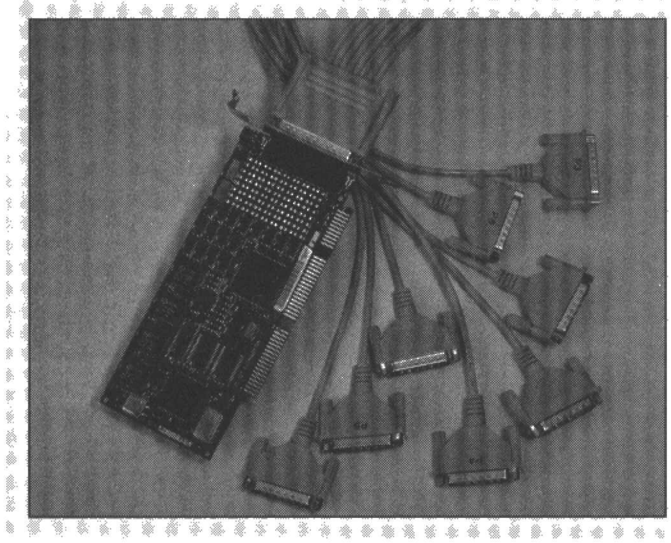
Artesyn Technologies is one of the largest providers of power supplies and power systems in the world.

For further information, contact Jackie Day, Artesyn Technologies, Springfield Industrial Estate, Youghal, Co. Cork, Ireland. Tel +353 24 25272 Fax +353 24 93510 email Jackie.day@artesyn.com



Multi-Channel 4 and 8-Port Serial Comms Boards

Keithley Instruments has announced its MetraByte Digi-Port Series of four-and eight-port power serial communication boards for use with ISA-bus-equipped PCs. These boards provide asynchronous, intelligent, high-speed multi-channel serial communication with a microprocessor for onboard serial I/O processing.



The Digi-4Port and the Digi-8Port provide an easy way to connect multiple peripheral devices to a PC via the serial bus. The series supports Windows95/98 and WindowsNT operating system platforms.

The boards can be used to interface to high speed modems, printers, networks, or other peripherals over a serial port. They are well suited for high speed remote LAN access and Windows multi-user communications.

Each board has a 16-bit Intel 12.5MHz 80186 onboard processor that undertakes serial I/O processing, saving the host PC's own CPU those tasks. Four 8-bit registers facilitate communications with the onboard microprocessor. The onboard Digi-Port firmware includes a high-level shared memory interface for optimal performance as well as extensive diagnostic capabilities. The handling of I/O tasks on board enhances response time, throughput and overall performance. The Digi-Port series supports full modem control and hardware handshaking on all channels.

The boards allow serial communication up to 4000 feet and at data rates up to 115.2 Kbaud - significantly higher than direction connections to the PC's standard COM1/COM2 ports.

For more information, contact Keithley Instruments Ltd., The Minster, Portman Road, Reading, Berks RG30 1EA. Tel 0118 9575666 and fax 0118 9596469.

OVERSEAS READERS

To call UK telephone numbers, replace the initial 0 with your local overseas access code plus the digits 44.

Power management on the Global Green Cat

Designed to be the First Solar Circumnavigator, the Global Green Cat project is the bold attempt by a thirty-four year old woman, Karen Howarth, to circumnavigate the globe in a 13.9-metre (45.5-ft) catamaran powered only by the output of photovoltaic solar panels.

Tony Howarth

This objective is attainable and it certainly should be timely. There is now little doubt that within twenty-five years, solar power will revert to its traditional place by becoming the new 21st-century icon for energy, in the same way that oil became symbolic of modern energy early in the 20th century.

The large oil companies are already the major players in the technology and production of photovoltaic modules. That should tell us something.

But, regardless of the future strength of photovoltaic (PV) based industry, Karen's ambition is currently right on the margin, as befits any worthwhile record attempt. In the context of a solar-electric circumnavigation, the term 'power management' is almost an oxymoron. With not even 2,000 watts (less than 3 horsepower) available round the clock, and that only with clear sunny weather, one could reasonably ask:

"What power is there to manage, anyway?"

The parameters

The calculations for Karen's project start with the route and the weather.

A boat designed for continuous solar electric operation must be extremely light in weight to compensate for the scarcity of power and for the considerable weight of the drive system. For safety the route and weather window for the voyage must include the minimum possibilities for gales and no chance whatsoever of tropical storms or hurricanes.

Equally, a solar boat needs good direct sunshine - every day. Cloud will reduce power by 60 percent to 90 percent and, although Karen's boat has no sails, she still prefers fair winds and currents to help her progress around the globe.

So there is only one route and one weather window combination completely suitable for Global Green Cat. Starting from the UK in late March or early April, Karen must circumnavigate via Panama and have the capability to return within 200 days.

The required average speed for over 26,000 nautical miles is therefore about 6 knots. This is a seriously fast and punishing circumnavigation. The last two women who have tried to break the East-West and West-East single-handed circumnavigation records under sail (by the more difficult but considerably shorter southern ocean routes) each took over 300 days.

90 percent of the voyage will be between 40 degrees north and 10 degrees south during the Northern Hemisphere summer. The most difficult parts of the voyage are, without doubt, the first and last 750 miles out of and back up the English Channel. This is allowed for, and average speeds on some days as low as 2 to 3 knots are expected. Even an occasional day going backwards can be accepted!

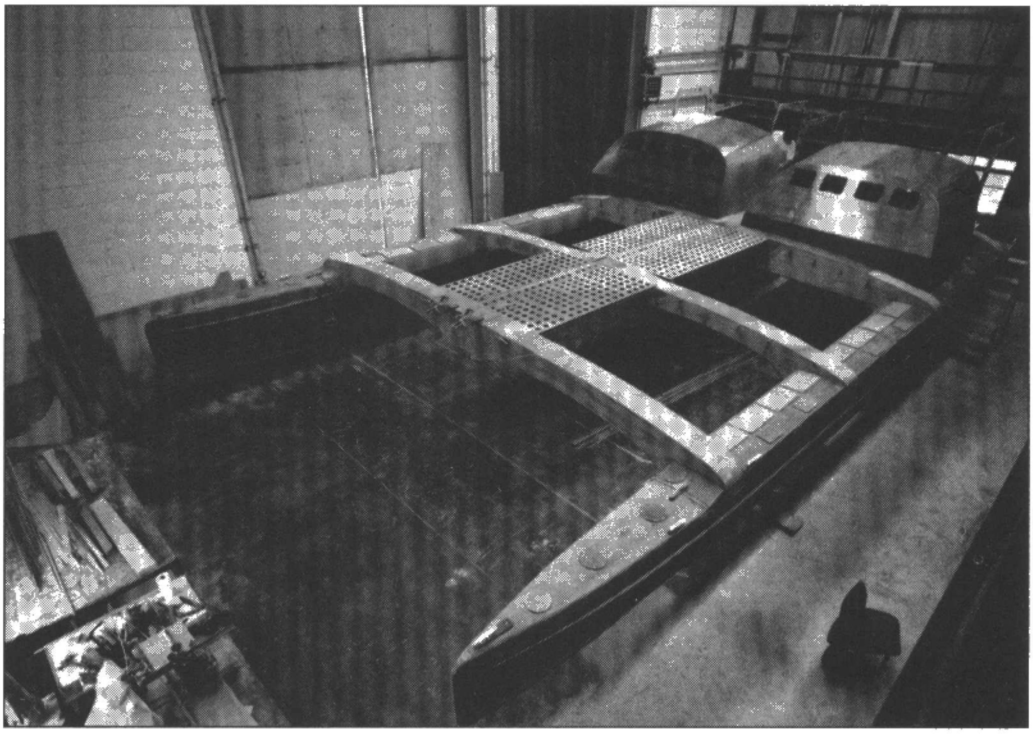


Figure 1: Global Green Cat under construction

The solar drive options

There are three distinct types of photovoltaic drive systems suitable for boats: direct drive, battery driven and continuous operation.

1. Direct drive.

In direct drive, the output of the PV modules is matched directly to the drive motor requirements. The use of a limited battery capacity provides a buffer. A well-known example of this method is the Trans-Australia solar racing cars.

2. Battery driven

Where batteries are a major part of the system, the drive motor runs off storage batteries and the PV modules provide all the charge for the batteries. If normal travelling time is less than parking, time the PV array can be appropriately smaller than is required for direct drive. A not-very-well-known but very workable example is my own much-used 'solar' dinghy.

3. Continuous drive

With continuous drive, the PV array is powerful enough to drive directly during daylight hours while producing enough surplus to recharge a bank of batteries of sufficient capacity to drive through the night. The example I am going to talk about is, naturally, the Global Green Cat.

I must add that in practice, all solar drive systems tend to blur the edges of these categories. Few attempt, as Global Green Cat does, to conform so rigorously to Category 3, day after day after day for six months or more.

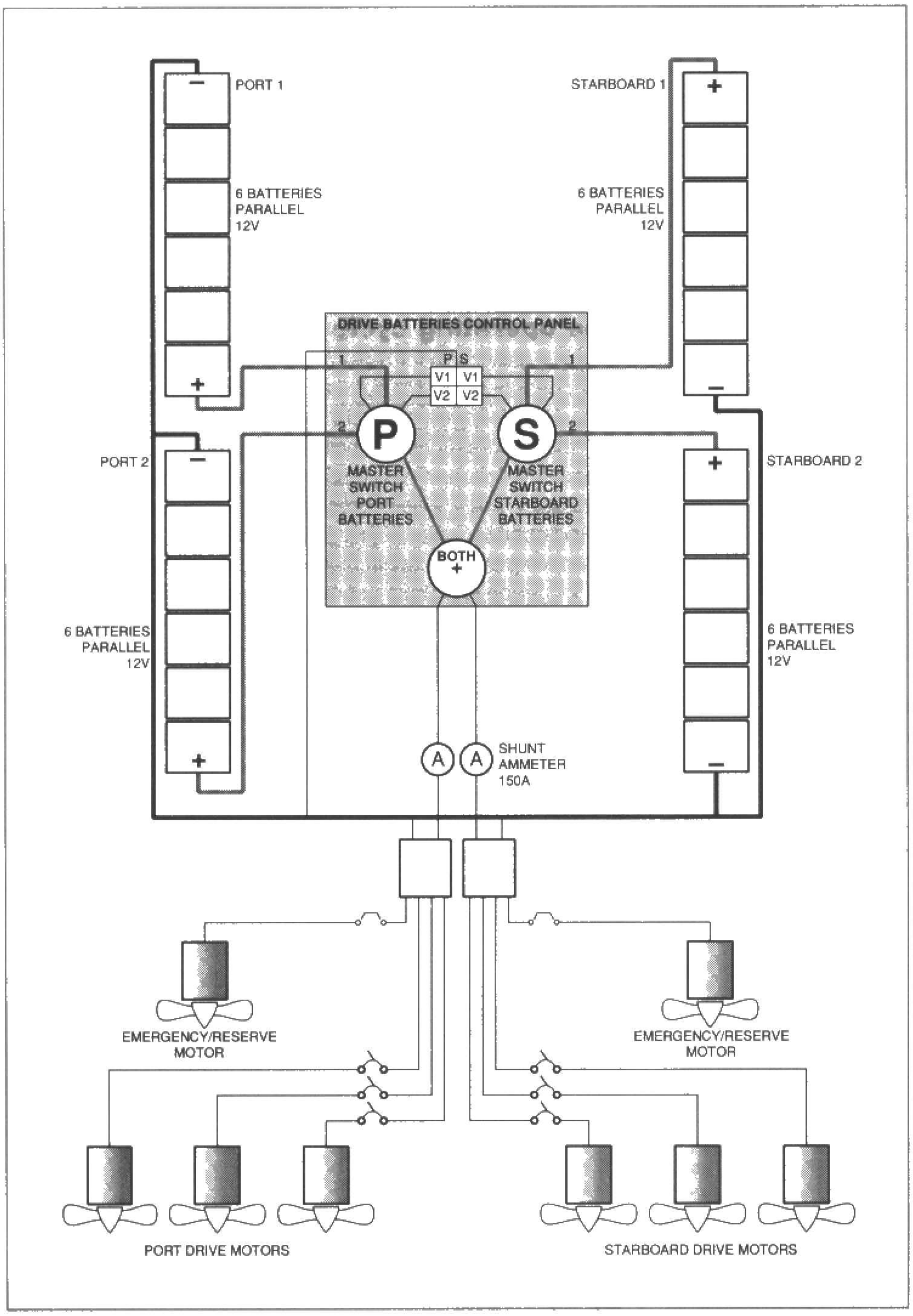


Figure 2: power available from the batteries to the drive motors

Drive motor options

The normal installed capacity includes three motors in each hull with a basic output of about 220 lb or 100 kg thrust for a draw of 220 amps. (These are our own measurements. The manufacturers claim and insist on 250 lb thrust for 216 amp draw at 12.8 volts. Hopefully they are right; no doubt the discrepancy is due to test conditions.)

In addition another two motors can be mounted quickly in wells in the cockspit, turning Global Green Cat into effectively a direct drive boar with a thrust of perhaps 336 lb or 153 kg for a draw of 288 amps; well within the approximate 340 amp maximum capacity of the PV array.

This is another part of the design balance, and offers, for safety purposes, still water speeds possibly as high as 10 to 12 knots on a sustained basis in sunlight.

PV output

Apart from direct sunlight the two most critical factors for good PV performance is that there should be absolutely no shading whatsoever of even part of one cell in the module, and the module should be orientated towards the sun. Global Green Cat has its communications mast on the south (port) side for a summer season westerly circumnavigation and the panels are tilted 5 degrees northwards.

The modules should peak at 21.25 watts, but each module has to be protected by a locking diode which reduces output under standard test conditions to a little over 20 watts. At sea on the chosen route the air is generally very clear compared to any sea level land-based situation. This is reflected in an enhanced PV performance at sea at all latitudes.

From experience in the tropics, all panels are expected to exceed manufacturer's peak claims by about 10 percent for 2 to 3 hours before and after noon. The anticipated 8 hours at manufacturer's peak are averaged to include this bonus (see **figure 2**). Dawn and twilight are, of course, very short in the tropics.

PV modules are temperature sensitive. Performance in the tropics can be enhanced by not laminating them or gluing them to a surface like the deck or cabin. Instead, there should be clear air flow past the backs of the modules.

In higher latitudes the output in summer is surprisingly similar to the tropics. The longer daylight hours and cooler air temperatures compensating for much of the loss of the sun's intensity (see figure 2).

The high output figures are forecast strictly for ideal conditions in the tropics. As output falls off for reasons of weather or location, there are five fallback possibilities:

1. Absorb the surplus contingent output
2. Deploy additional modules in predetermined positions above the cockpit, down the centre of the bridge deck and on the hulls. This is completely practical in fair weather.
3. Reduce power for part of the night to two motors and 4 knots (still 5 knots in trade winds).
4. Reduce speed during the day.
5. Stop while keeping some battery reserve for manoeuvring and wait for the sun! Or at least wait for the batteries to accumulate enough power from the PV output, however low, to be able to proceed.

Table 1: Global Green Cat - Main Drive Power Budget

Power used during the 60 percent discharge cycle expressed in watt-hours for a 24-hour cycle:	
3 motors overnight,	
90 amps at 12.3V - 13 hr	14,391 W/hr
3 motors 1st daylight neutral 1.5 hr	
108 amps at 12.8V - 1.5 hr	2,074 W/hr
3 motors 4 hr first-stage charging	
100 amps at av. 13.6V - 4 hr	5,984 W/hr
4/5/6 motors 4 hr second-stage charging	
190 amps av. at 13.6V - 4 hr	10,336 W/hr
Second neutral direct drive 1.5 hr	2,074 W/hr
To house batteries 50W for 24 hr	1,200 W/hr
Total	**-34,859 W/hr**
Power used during the 80% discharge cycle expressed in watt-hours for a 24-hour cycle	
4 motors overnight,	
120 amps at 12.2V - 13 hr	19,032 W/hr
4 motors 1st daylight neutral 1.5 hr	
144 amps at 12.8V - 1.5 hr	2,765 W/hr
4 motors 5 hr first-stage charging	
150 amps at av. 13.6V - 5 hr	10,200 W/hr
5/6 motors 3 hr second-stage charging	
180 amps av. at 13.6V - 3 hr	7,344 W/hr
Second neutral direct drive 1.5 hr	2,765 W/hr
To house batteries 50W for 24 hr	1,200 W/hr
Total	**-43,306 W/hr**
Power generated in a 24-hour cycle:	
1.5 hour neutral (direct drive), say	2,500 W/hr
8 hour 20 watts per module	
288 modules	46,080 W/hr
1.5 hour neutral (direct drive)	2,500 W/hr
Total generated	**+51,080 W/hr**
Power used 60 percent discharge cycle	**-34,859 W/hr**
Contingent surplus	**+16,221 W/hr**
Contingency as percentage	**32 percent**
Power used 80 percent discharge cycle	**-43,306 W/hr**
Contingent surplus	**+7,774 W/hr**
Contingency as percentage	**15 percent**

It is not at all unusual for leisure boats powered by outboard petrol motors to embarrassingly (and dangerously) run out of fuel. It also happens to yachts with auxiliary engines, and to serious power boats as well. They can only wait to be towed in. At least a solar sailing boat can just wait to be recharged and then proceed with dignity under its own "steam".

The operating cycle

A typical daily cycle for most of the voyage will include about 8 hours of substantial PV output producing the charging surplus. This will be followed by about 1.5 hours of neutral operation with the motors running effectively on direct drive. Then 13 hours of twilight and darkness must be covered by the batteries. There will be another neutral 1.5 hours after sunrise.

An important point is that PV modules lose efficiency at higher temperatures so, in higher latitudes, cooler temperatures and longer daylight hours compensate substantially for the comparative lack of direct sunlight. My experience of working with photovoltaics under real ocean conditions has taught me two crucial lessons:

1. That balance is essential and is the essence of an effective PV powered system.

2. That whereas solar electric systems may still be marginal as far as power is concerned, they are far less delicate and sensitive than we had expected. The hardware is much tougher and more mature than the fledgling state of the 'solar industry' suggests.

Originally, I began 'doodling' with a catamaran of about 9 m and a crew of two. I ended up with a good balance based on known equipment and known PV performance on a 13.9-m (45.5-ft) by 7-m (23-ft) catamaran to be sailed single-handed!

A well known ship design software package confirmed that the fine hulls could be driven at about 6 knots by a thrust of 120 lb (55 kg) at the propellers, and that 90 to 100 lb thrust would provide 5 knots in still water increasing to 6 knots or more down wind and 'down' current in the trade wind belt.

The hardware

Choice of hardware is always a thorny subject, and especially

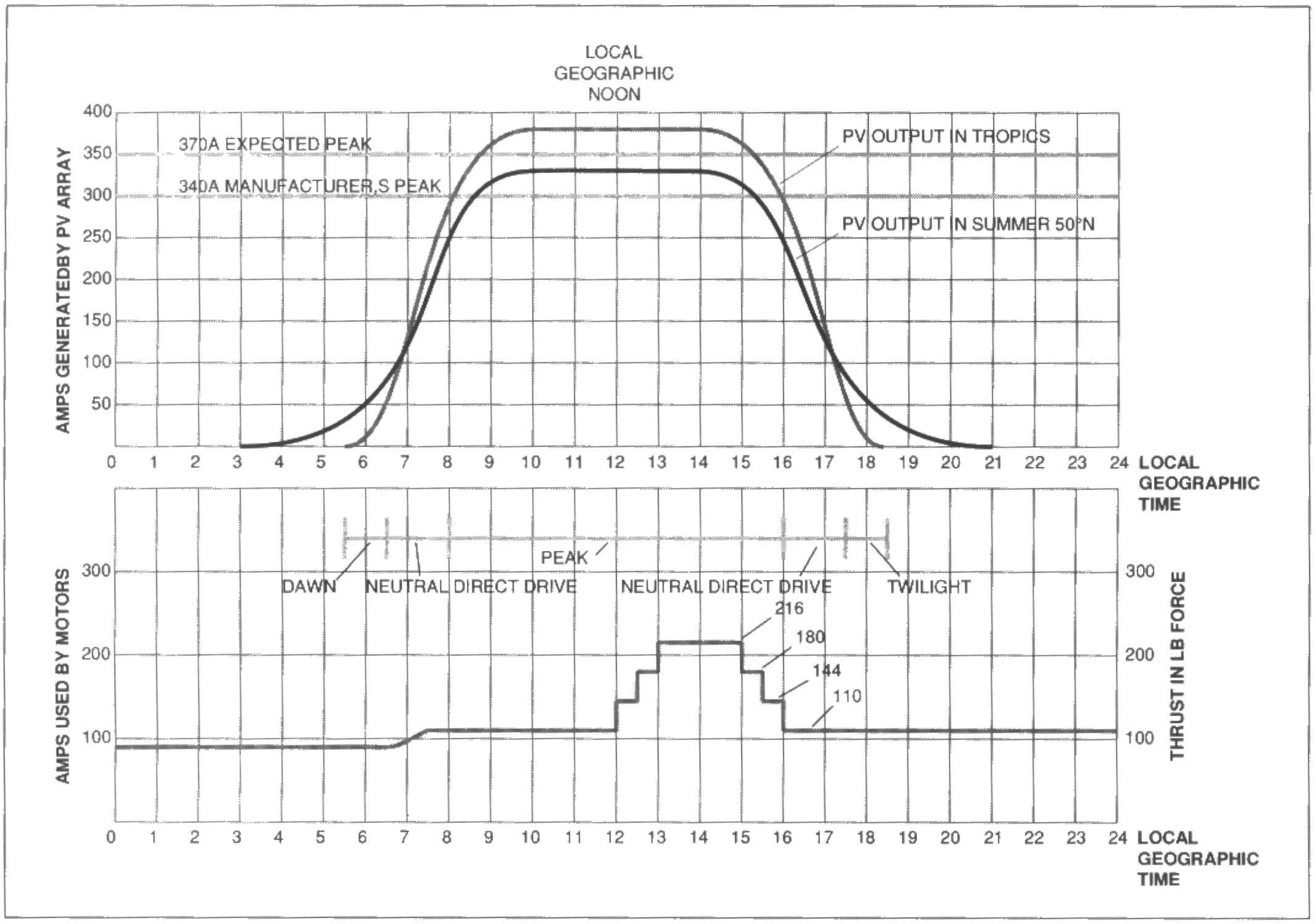


Figure 3: power generated by the PV array over 24 hours compared with the power used by the motors

so in a field were industry standards are hardly established and everybody is grabbing for a piece of something that does not yet really exist. From the beginning, the hardware had to be 'off the shelf' wherever possible due to budget constraints. (I found myself asking: What budget?). It had to be known to be reliable from our personal experience or the experience of other PV powered boat crews. 26,000 nautical miles around the world in a lightweight boat is no joke and no place to be experimenting with unknown equipment.

This is especially important in the extreme salinity of the seas in the tropical trade wind belt, a corrosive reality that has to be experienced to be believed. It starts with the plastic zips and goes downhill from there.

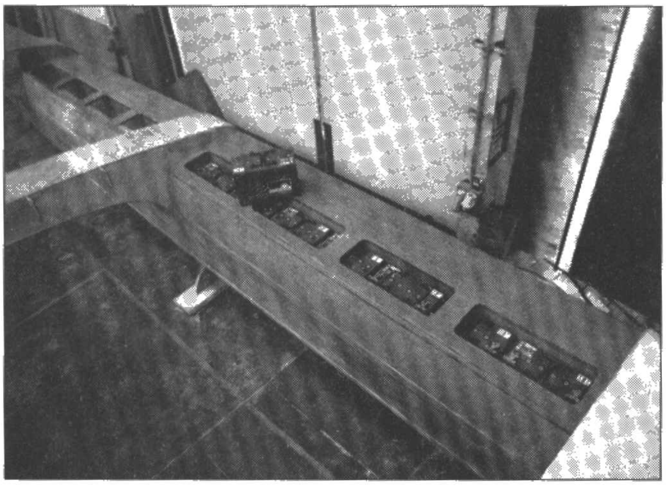


Figure 4: the batteries installed in the structure of the catamaran

Batteries

I chose Sonnenschein Dryfit gel batteries for a number of reasons:

* Excellent deep cycle capability for weight and cost even up to 80 percent discharge cycles

* They are completely sealed and will operate 'normally' even upside down and under water. (A scary thought, but a comfort too in the case of an inadvertent inversion, as Tony Bullimore discovered.)

* My personal experience of a 35 amp/hr Dryfit gel battery lasting five years as the single solar charged drive battery for a very active electric-powered ship's dinghy.

* My personal experience of a bank of four 80 amp/hr Dryfit gel batteries still operating satisfactorily after 7 years. These PV charged 'house' batteries are in use 365 days a year.

Motors

I chose Minn Kota 42 series electric outboards because:

* After five years saltwater tropical use I cannot fault the Minn Kota trolling motors and their amazing plastic weed-free propellers.

* The Minn Kotas are as efficient as most everything else available off-the-shelf. Better than 1 lb thrust per amp at 12.8

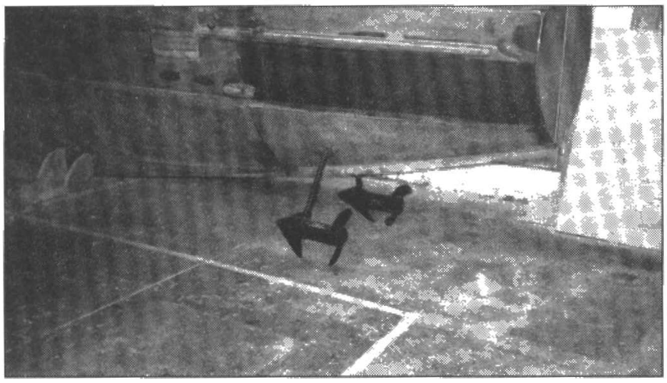


Figure 5: the Green Cat's twin propellers

volts and nearly 3 lb thrust per net lb weight.

* The newer 12-volt 42 series available in the United States is up to 20 percent more efficient than other larger 24-volt and older models in the range.

This choice of drive motors has lead to a 12-volt multi-motor configuration with two motors attached to each hull and one motor in each rudder, giving six motors providing six speeds and great manoeuvrability.

Solar panels

I chose specially laminated MS30-lite Solarex PV modules because of their light weight, suitable form and strength for foredeck mounting and because they have no restriction of cell efficiency. The modules also fit the boat's design well.

After the construction of the boat had started the specification of the MS30 panel was changed, resulting in a 22 percent increase in weight, but alternative stock panels do not fit the design well and are also all too heavy.

400mm x 400mm modules fit perfectly. Each module has nine 125mm x 125mm mono-crystalline high efficiency PV cells. Four modules in series will provide peak 4.75 amps at 17.5 volts under load, and up to 10 percent more in the tropics.

Global Green Cat - Performance

After conducting tank tests at full load for 14 hours to 80 percent discharge I conservatively consider that the chosen motors will use, on average, 30 amps each for an average 30 lb of thrust throughout the hours of darkness.

Applying my own formulae, I came up with two plans both within the capabilities of the gel batteries.

Plan 1: assuming a 60 percent discharge cycle.

Three motors provide an average 90 lb thrust overnight, resulting in a speed close to 5 knots, increasing in the trade wind belt to 6 knots or more.

The three motors will use on average 90 amps. The overnight amp/hr requirement is:

13 x 90 = 1170 amp/hr

At 60 percent overnight discharge, the gross battery capacity required is:

1170 x 100/60 = 1950 amp/hr

or, say, 24 x 80 amp/hr batteries.

(The current drawn from each battery is under 5 amps, ensuring full amp/hr capacity.)

In the mornings the motors will be running at higher voltages than at night and will use about 20 percent more current than overnight. The first four hours of the day should bring the batteries from about 60 percent to 20 percent discharge level. That means replacing around:

40/100 x 1920 = 768 amp/hr.

or a charging current over four hours of 1920/10 = 192 amp. So the total current required from the PV array is at least:

1.2 x 90 + 192 = 300 amp

We need, say, 288 of the 400mm x 400mm modules, total weight less than 300 kg (compared to an insupportable 450 kg for equivalent stock panels). The total panel area of 46 square metres is comfortable for Global Green Cat. The panels fit neatly and do not 'swamp' the boat as some earlier plans did.

After about four hours the regulators will start to cut in to moderate the charging voltage. At this point, Karen must become a 'power manager' by simply switching on, as appropriate, more drive motors.

The simple power management process could be controlled electronically as an adjunct to the regulator circuits and, no doubt would be on a fully developed Solar Sailing boat. Our problem with automatic electronic control is that Karen does not want to be surprised by a sudden increase in power of perhaps 50 percent while dodging a bevy of fishing boats or a super-tanker.

Together the six main drive motors will provide at least 220 lb (100 kg) thrust and sustained over-the-ground speeds of 8 knots.

Plan 2: assuming an 80 percent discharge cycle.
An 80 percent discharge cycle potentially allows use of four motors and 120 lb thrust all night and about 150 lb thrust all morning. The rapid charge period would be extended by an

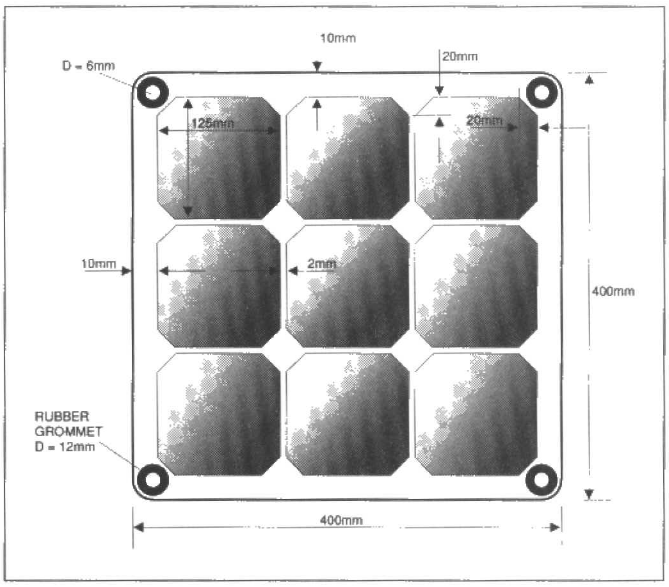


Figure 6: Global Green Cat's photo voltaic module

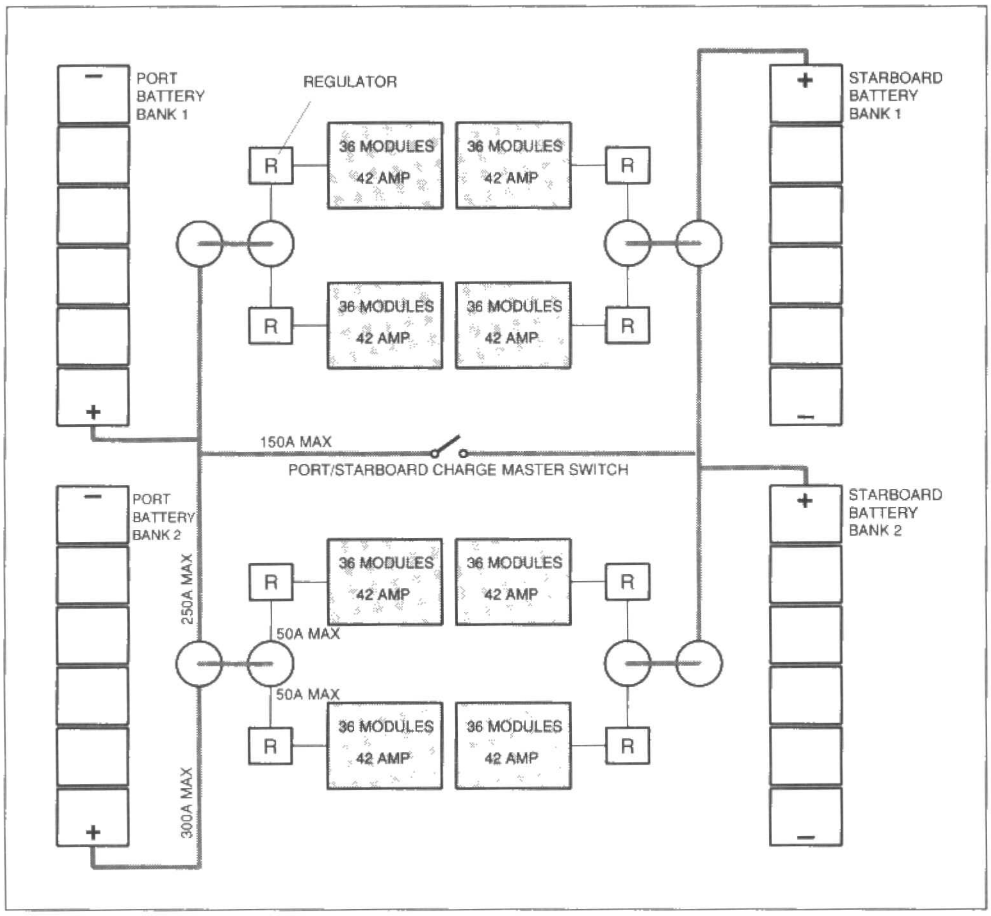


Figure 7: the charging circuit for the master battery switches

hour or so and the finish charging period reduced. Again, we have six motors and more than 220 lb thrust in the afternoon.

An 80 percent discharge cycle could mean, on average, an extra knot of speed. The difference one knot makes in total voyage length is 30 days. Returning one month earlier means improved sunlight for the return up the Channel and 30 less cycles for the batteries and frankly, for Karen, 30 less lonely days at sea in a lightweight boat. The 80 percent discharge cycle will probably be used in the trade wind belt. The 60 percent cycle may be more suited to higher latitudes.

Accuracy and safety margins

The amp/hr-based calculations are crude. They compare, for instance, charging amps at charging voltages as high as 17.5 volts with battery amps at voltages as low as 11 volts. At this stage of development this is not a bad technique, as it builds in a considerable margin for less than efficient processes and compensates for the unexpected. For cross checking with gross watts generated to gross watts utilised I find a 32 percent surplus for the 60 percent discharge cycle, a total of over 50 kilowatt/hours generated against less than 35 kW/h used by the motors.

This margin must be set against system losses, variations in panel angles due to wave action, inevitable salt accumulation on the panels and, on the longer stages, underwater fouling of the hulls. Equally, PV module over-performance in the tropics could increase the margin. Any difficulties are likely to have more to do with the relationship between the thrust generated and hull performance in the truly chaotic systems of sea state and weather.

Only after-the-fact analysis can attempt to create order and predictable accuracy out of the chaos. That, of course, is a major part of Global Green Cat's mission. Before the fact we are still working on a basis of theory and instinct tempered by experience and as much redundancy as possible.

The wiring arrangement provides an additional safety margin. Its built in redundancy allows for complex manipulation of charge, storage and drive motor combinations.

The solar panels are wired in eight discrete banks each with a 50-amp regulator. The batteries are in four banks of six. There are, in addition to the six installed motors, two spare motors mountable through wells in the cockpit. Switching allows almost any combination of panels, batteries and motors to be used or isolated as required. There are also ten scheduled 24hr/48hr stopovers on the route during which the batteries can be thoroughly floated off.

More than twenty watertight compartments and a full compliment of communication and off-shore emergency equipment completes the safety provisions.

House power and instrumentation

'House' power is something of a joke aboard Global Green Cat. Facilities are minimal. The 'crew' is only permitted to add the weight of a passport because the lack of one might cause delays. Global Green Cat is definitely a "two pairs of knickers only" boat - one to wear and one to wash. Books must be changed at stopovers. Cooking is by a two-burner canister-type alcohol stove (clean 95-percent plus, not methylated spirits). There are few luxuries, such as a small 25-watt Electrolux refrigerator and a Discman CD player with power amp and speakers and the inevitable small battery operated Sony short-wave radio for the BBC World Service. That is about it.

Navigation is by GPS (one installed, two portables as back up). Use of communications equipment is as restricted as possible. Charting, Weather-fax, Navtex and written log are on PC laptop with a large colour screen, this will be booted up only as required. A second low power notebook will be available for continuous monitoring and recording of all kinds of data.

Experience suggests that 'house' power for an efficient ocean going boat can realistically amount to about 100 watts around the clock (see table 2). Including the monitoring facility and daily communication with base and the Internet, Global Green Cat may need an average closer to 150 watts.

The two 80 amp/hr 'house' gel batteries are charged by their own 170 watts of dedicated PV modules and a 50-watt wind generator. Any shortfall will be made up by trickle charging via blocking diodes and suitable resistances from the main battery banks.

Early on, it was decided that Global Green Cat would be purely a Solar Sailing boat. Wind generator assistance would not be used for the drive system. But the use of wind generation for the 'house' electrics also allows monitoring of wind generated output in relation to PV performance over the whole route.

There is a saying: "Apart from the sails, anything you put on a boat makes is slower."

As Global Green Cat carries no sails at all, we are already in trouble according to this yardstick, and every pound of weight is a liability as is every milliamp drawn by the "house".

A first step is to disable almost all panel indicator or warning lights. With DC circuits and incandescent bulbs at 0.06 amps of 0.75W each, these insignificant bulbs might take an average of 15 to 20W or more continuously on a boat our size. That is about twice what we are allowing for the use of the navigational laptop computer.

House battery and PV capacity

The house battery capacity is kept small to save weight. If weight was not a consideration the capacity would be increased to at least 400 A/hr and the number of house PV modules would be increased to at least 24, with a capacity of 480 watts. The much lower installed capacities are designed to provide essential power in an emergency and otherwise to be continually topped up from the drove power system.

It is practice and important on boats to use dual wiring throughout. Unlike cars or engines, chassis or blocks or hulls or copper grounding strips should not be used as common returns, nor is it good practice to locate common negative bus bars around the boat.

The reasons are to do with serious corrosion probabilities and the possibility of unwitting errors of accumulated overloading of the common negative return. Thus, all circuits should be assumed to be individual with matched negative and positive wires both connected directly back to the distribution boards or master switches or batteries.

Navigation area lights are split between two breakers and the computers are split between two distribution boards. Nothing other than monitoring equipment shares the distribution board with the monitoring computer.

The inverter takes up to 100A and is accorded its own board. Bilge pumps also take up to about 100A if used together, and they have their own separate board connected directly to the batteries.

Fuses

Fire at sea is, if anything, more frightening and deadly than fire on land. It is normal on boats for every primary circuit, every secondary circuit and every single piece of equipment to be separately fuse-protected. In the case of Global Green Cat, with a relatively massive battery capacity, capable of producing thousands of amps if shorted out and the solar panel array capable on its own of producing 300A, fusing and general protection against short circuiting is paramount.

The primary circuits will be double-protected with trips on the positive side and fixed fuses on the negative (just in case the trip fails).

The individual fuses are often very particular and so have, for the most part, to be fixed glass fuses. However I prefer to use trips for secondary circuits and for lighting.

Glass fuses endlessly suffer from corrosion. Plastic screw caps, however often Vaselined, seize up. So do bayonets. It is advisable to clean and re-grease every glass fuse once a week. Once a month can be too long.

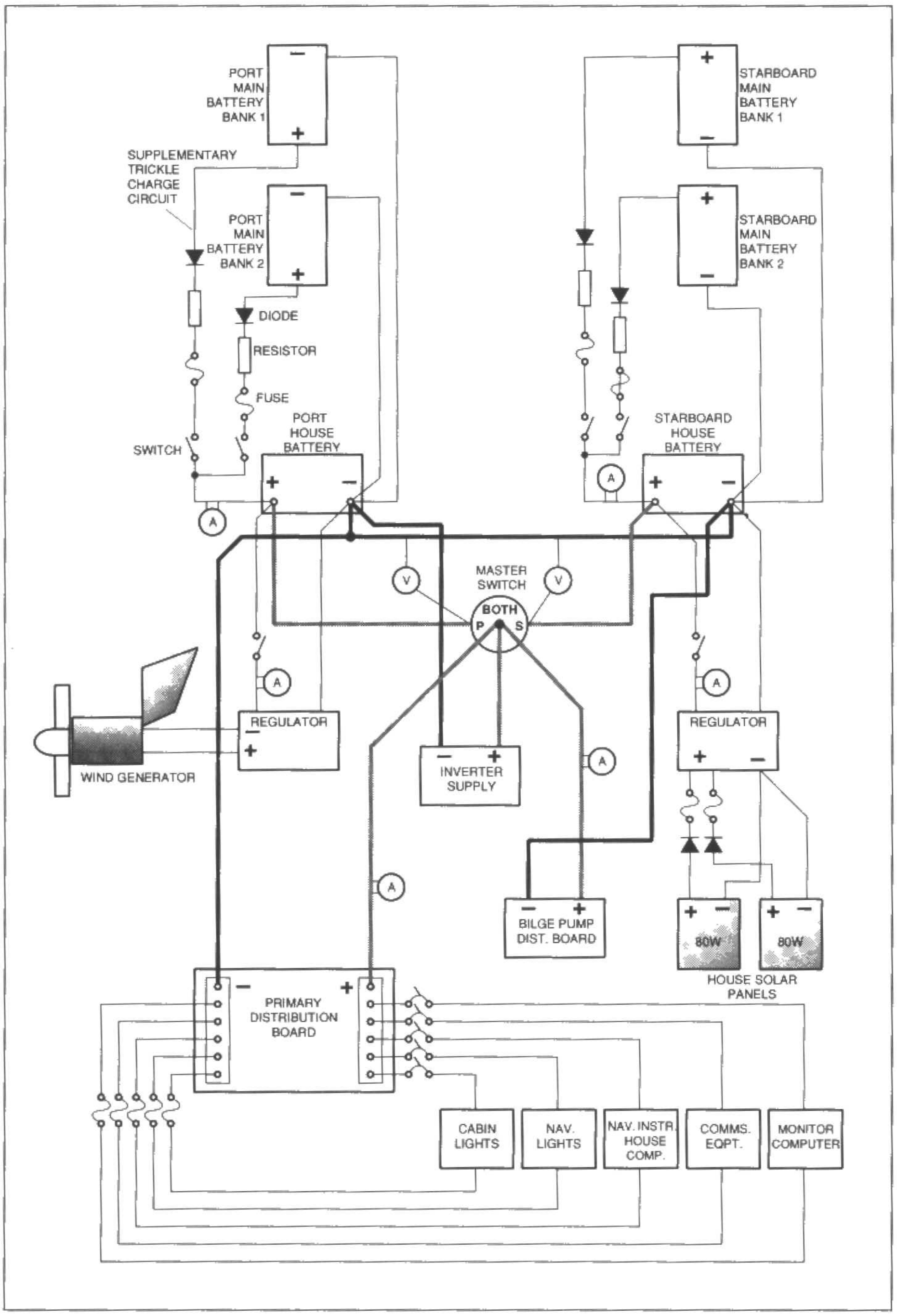


Figure 8: the House Wiring charging circuits

Table 2: Global Green Cat - House Power Budget

Watts used continuously calculated by averaging usage over a 24-hour period.

Cabin lights	**Load**	**Duration**	**Energy**
Port cabin:			
Galley area			
2 x spot	2 x 10W	01.0hr	01.0W/hr
1 x flood	20W	02.0hr	01.7W/hr
Bunk area			
1 x flood	20W	01.0hr	00.8W/hr
1 x spot	10W	02.0hr	02.0W/hr
Starboard cabin:			
Navigation area			
1 x spot	5W	12.0	02.5W/hr
2 x spot	10W	02.0hr	00.8W/hr
1 x flood	20W	02.0hr	01.7W/hr
Storage area			
1 x flood	20W	01.0hr	00.8W/hr
1 x spot	10W	01.0hr	00.4W/hr
Instrument lights:			
Control panel	05W	12.hr	02.5W/hr
Compass	2 x 2W	12.0hr	02.0 W/hr
Inspctn light	20W	01.0hr	00.8 W/hr
Switch indicator lights			disabled
Navigation lights:			
Emergency strobe	5W		N/A
Emergency spotlight	50W		N/A
Red/green/green	25W	12.0hr	12.5 W/hr
Stern light	10W	12.0hr	05.0 W/hr
Motoring light	25W	12.0hr	12.5 W/hr
Anchor light	10W		N/A
Galley equipment:			
Shower pump	12W	00.1hr	00.1 W/hr
Refrigerator	24W	24.0hr	24.0 W/hr
Maintenance equipment:			
Bilge pump	4x250W		Normally N/A
1000W inverter for power tools and other 240V devices eg hair dryer but only when in port		N/A	
Navigation equipment:			
Log and wind speed/ direction and depth	4W	24.0hr	04.0 W/hr
GPS (installed)	4W	24.0hr	04.0 W/hr
Radar	24W	01.0hr	01.0 W/hr
Autohelm	4W	24.0hr	04.0 W/hr
Large colour display laptop for:			
Weather fax			
Navtex			
Charts			
Written log	36W	06.0hr	09.0 W/hr
Printer	10W		N/A
Communication equipment:			
Satellite communications:			
TBD allow	120W	01.0hr	05.0 W/hr
VHF	4W	24.0hr	04.0 W/hr
SSB rec.	4W	04.0hr	00.7 W/hr
SSB trans.	200W	01.0hr	08.5 W/hr
Monitoring:			
Small display laptop for recording data:	20W	24.0hr	20.0 W/hr
Total:			131.3 W/hr
"House" power summary:			
(Watts used continuously while at sea)			
Cabin lights		18.9 W/hr	
Equipment lights		5.3 W/hr	
Navigation lights		30.0 W/hr	
Galley		24.1 W/hr	
Navigation equipment inc. computer		22.0 W/hr	
Communication equipment		18.2 W/hr	
Monitoring computer		20.0 W/hr	
Contingency, say		18.7 W/hr	
Total:		150 W/hr	
Average power available			
Dedicated "House" PV output 170W peak		60 W/hr	
Wind generator average		40 W/hr	
Total		100 W/hr	

If needed the shortfall of 50 W/hr is drawn from the main traction batteries.

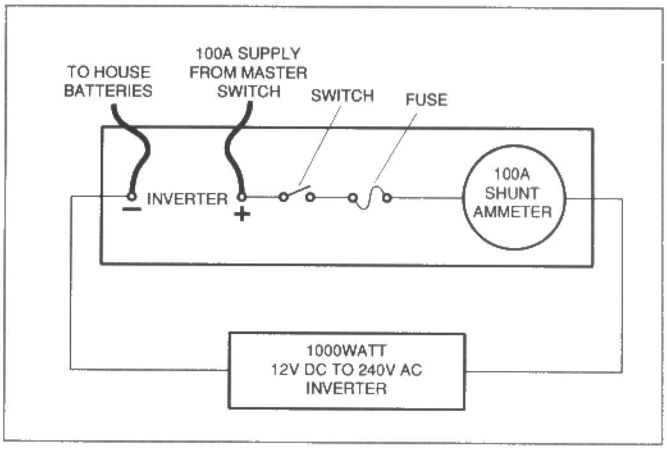

TO HOUSE BATTERIES
100A SUPPLY FROM MASTER SWITCH
SWITCH
FUSE
INVERTER
–
+
100A SHUNT AMMETER
1000WATT 12V DC TO 240V AC INVERTER

Figure 9: the distribution board and inverter supply

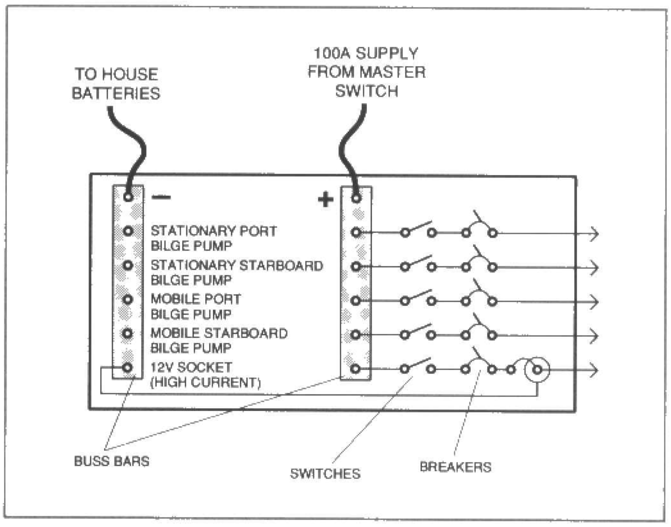

TO HOUSE BATTERIES
100A SUPPLY FROM MASTER SWITCH
–
+
STATIONARY PORT BILGE PUMP
STATIONARY STARBOARD BILGE PUMP
MOBILE PORT BILGE PUMP
MOBILE STARBOARD BILGE PUMP
12V SOCKET (HIGH CURRENT)
BUSS BARS
SWITCHES
BREAKERS

Figure 10: the distribution board: to the bilge pumps

Conclusions

Putting aside the frivolous though laudable objective of setting a record for a first 'solar' circumnavigation, there are more serious objectives to the voyage of Global Green Cat. The idea of the project has always been to collect relevant solar sailing data from a wide range of latitudes and seasons. And then, hopefully, to assist a suitable partner/sponsor with the development of power and route management software for solar sailing boat navigation.

For instance, a future solar sailing boat management system should be able to scan satellite pictures for cloud cover and re-route the boat while taking note of trends and maintaining battery reserves. Commercial shipping routes in the age of oil powered cargo vessels are different from the shipping routes of the age of sail, and different even from those of the age of coal. There is little doubt that routes in an age of solar powered or hybrid solar powered shipping will need to be different again.

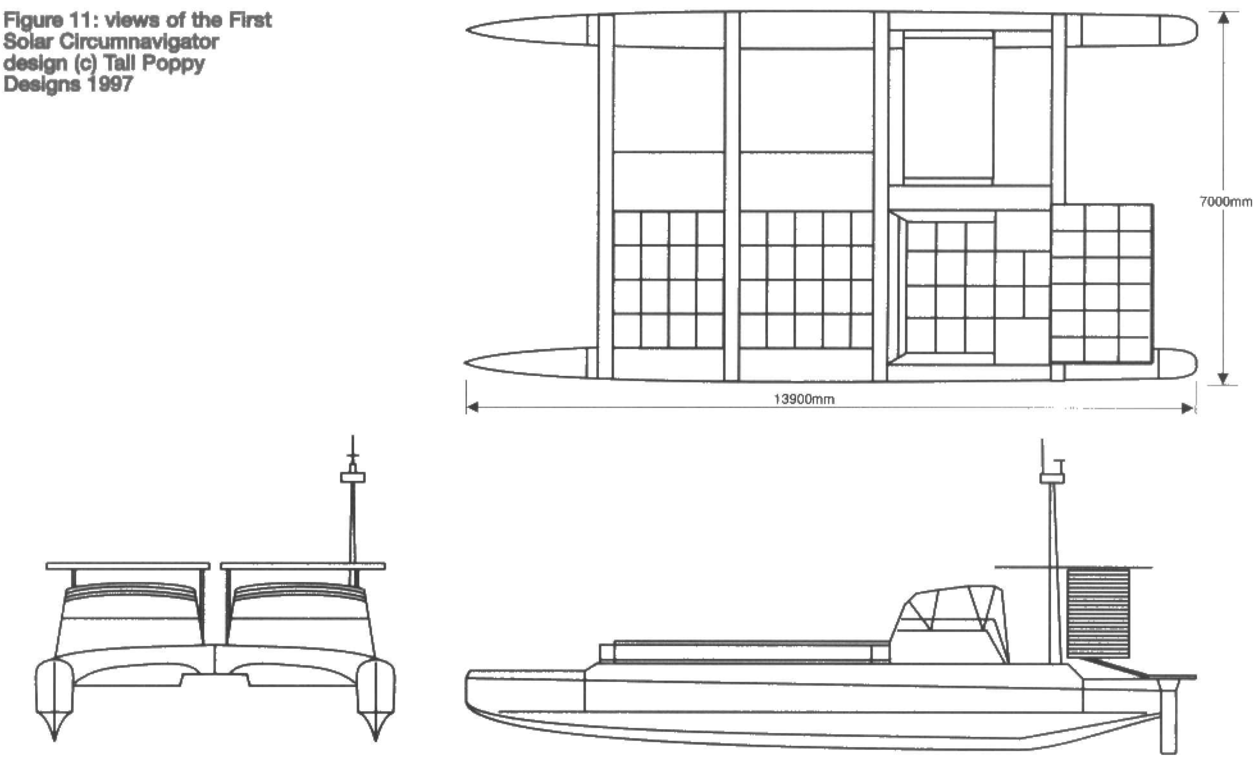
It is hoped that Global Green Cat can contribute to an age of Solar Sailing by collecting original data and by inspiration.

Endnote!

This article was written on a PC powered from solar panels on board a boat in which the 'house' power has been generated by PV modules and a small wind generator since 1990.

An earlier version of this article appeared in Electronic Engineering, Miller Freeman Plc, September 1998. Original material by Tony Howarth and CMP Batteries Standby Division © Tony Howarth.

Figure 11: views of the First Solar Circumnavigator design (c) Tall Poppy Designs 1997



Karen and Tony Howarth are still seeking sponsorship to complete the Global Green Cat's Odyssey. Potential sponsors can contact them via ETI's editorial address (page 74 of this issue).

NEXUS

NEWS FROM THE NEXUS PHOTOSTAT SERVICE.

The Nexus Photocopying Service can provide you with all those interesting features and valuable projects that have been published in your favourite magazine. The new costs of our photocopying service are as follows:-
First article: £2.75 inc of VAT. Please note that projects published over several issues must be ordered as a series of individual articles, each for £2.00.
A £2.75 search fee is required if full information is not supplied.
Please note delivery could be up to 28 working days.

Please supply photo-copies of the following articles from
(Complete in BLOCK CAPITALS)

Month .... Year .... Page (if known) ....
TITLE ....
Month .... Year .... Page (if known) ....
TITLE ....
Month .... Year .... Page (if known) ....
TITLE ....
I enclose a cheque/postal order made out to Nexus Special Interests to the value of:
£ .... P&P £1.00 (UK only) 20% Overseas
Total remittance £ ....

Name: ....

Address: ....

....

.... **Post Code:** ....

Send the complete form and remittance to:
Photocopy Service, Nexus Special Interests, Nexus House,
Azalea Drive, Swanley, Kent BR8 8HY.

Video Surveillance

Pinhole Board Camera (B&W) 12v DC, 0.1LUX, 380 TV Resolution
Size: 35mmx35mm **£35.00**

Pinhole Board Camera (Color) 12v DC, 0.5 LUX, 420 TV Resolution 2 board foldable
Size: 40mmx40mm **£190.00**

Audio/Video Transmitter module
12v DC, 4 Channel Selection
900Mhz-1200MHz, FM Modulation
£120.00

4 Channel Receiver + Switcher
12v DC, Composite Audio/Video
Output **£150.00**

TFT 4" Colour Monitor
12v DC **£150.00**

We also stock:
Time & Date Generator, Minature PIR etc.

All prices are subject to VAT

Confidential Communications Limited
344 Kilburn Lane, Maida Vale
London W9 3EF
Tel (44)(0) 181 968 0227 Fax: (44)(0) 181 968 0194
Email: 106075.276@Compuserve.com

PIC-Controlled MIDI Processor

The purpose of this project is to take in a MIDI signal, process it in one of a variety of ways, and retransmit it under PIC control. The functions are provided by software.

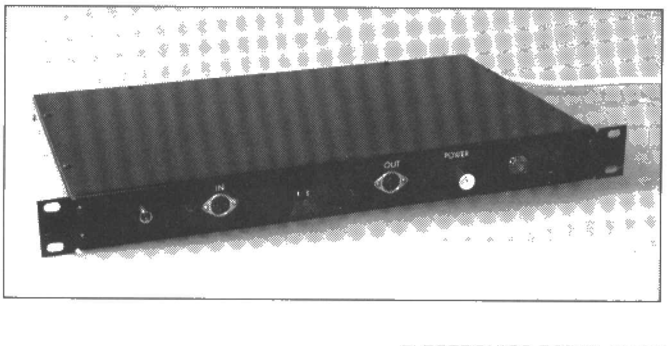
Robert Penfold

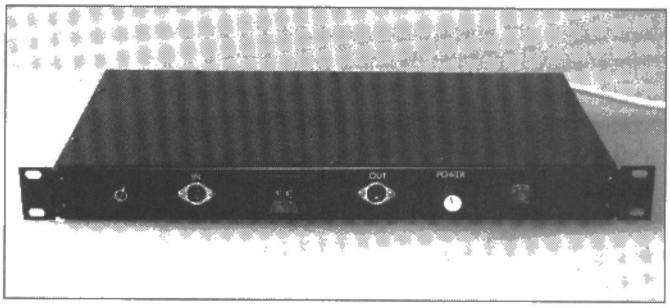
The processing of the MIDI data is controlled by a PIC processor (**figure 1**), and the functionality of the unit is governed by the software rather than the hardware. With the sample software provided, the unit gives a kind of harmoniser action with the pitch value of received notes being shifted up or down by anything from zero to 15 semitones. One way of using the MIDI processor is to connect it between a master keyboard and a slave instrument. The slave instrument will then follow the playing on the master keyboard, but with all the notes shifted up or down by the selected amount. This will provide nice harmonies or excruciating results depending on the amount of shift selected.

With most single MIDI keyboards it is possible to take the MIDI output signal, process it, and then feed it back into the MIDI input port. The instrument then harmonises is with itself, playing the normal and shifted notes each time a key is operated.

There are numerous other MIDI functions that the unit could provide with suitable software in the PIC processor. Messages on one channel could be shifted to another, or messages on any channel could be moved to the selected channel. The processor could be used to provide MIDI filtering, with a certain type of message being removed completely. The sample MIDI filtering program provided here removes pitch-bend messages on any MIDI channel. Within reason, the same hardware can be made to provide practically any form of MIDI signal processing simply by using a suitable program in the PIC processor.

It is not possible to provide a full range of programs to cover all eventualities here, but most types of signal processing require only quite simple software. Anyone with a reasonable knowledge of PIC programming and MIDI coding should have little difficulty in producing extra software for this device. Things are made easier by having a UART to handle the serial to parallel and parallel to serial conversions. The PIC processor therefore only has to deal with bytes of parallel data that are easily processed. It also has a few hundred clock cycles available to deal with each byte of data, which means that there is plenty of time available if some form of complex processing is required.





System operation

MIDI uses a form of serial signal coding that is in many ways like the standard RS232C system used in computer interfacing. However, rather than using positive and negative voltages to represent the two logic levels, MIDI uses a simple current loop system with a five-milliamp current being switched on and off. This current is used to operate the LED in an opto-isolator at the input of the receiving device. The opto-isolation helps to avoid the problems with the hum and earth loops that can easily occur when several pieces of audio equipment are connected together. It also helps to prevent digital noise from finding its way out of the logic circuits and into the audio signal path. MIDI operates at a baud rate of 31250, which is higher than the normal maximum RS232C rate of 19200 baud. This rate is still well within the capabilities of any normal serial interface chip. In this case the serial to parallel and parallel to serial conversions are performed by an industry standard 6402 UART (universal asynchronous receiver/transmitter). The receiver section is fed with the input signal via a fast opto-isolator that provides the UART with a signal at normal logic levels. The transmitter section drives output by way of an inverter and an open collector switching transistor. A clock signal controls the baud rate of the UART, and this signal must be at 16 times the required baud rate. In this case a clock frequency of 500 kHz is required. This signal is provided by a 4-MHz crystal clock circuit and a three-stage binary divider circuit that provides a division by eight.

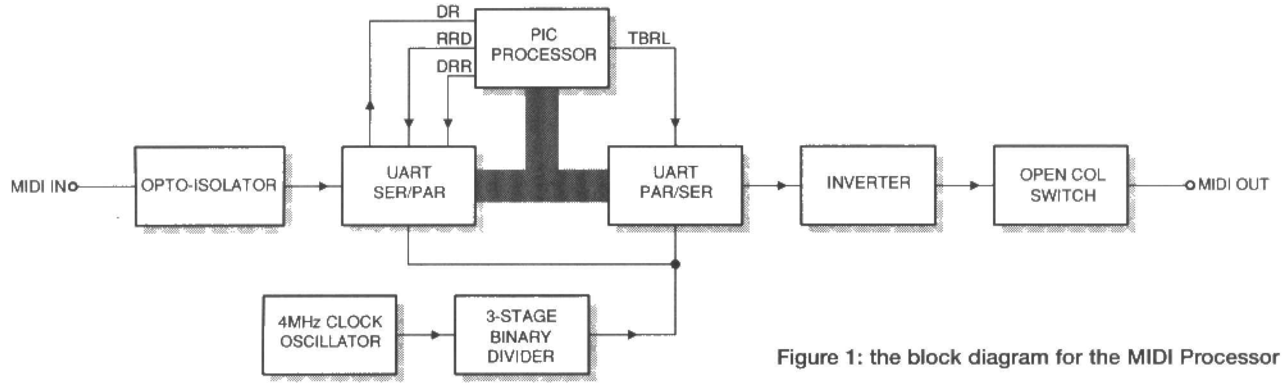


Figure 1: the block diagram for the MIDI Processor

The PIC processor provides the control logic as well as any data processing that is required. When a new byte of data is received, the Data Ready (DR) output of the UART goes high. This status output is monitored by the PIC processor, and is reset by the processor supplying a pulse to the Data Ready Reset (DRR) input of the UART. This input is normally high, and is fed with a low pulse to reset the DR input. Having read in the new byte of data, the PIC processor must disable the outputs of the receiver section of the UART so that it can place data onto the data bus itself. Although at first sight this may seem to be pointless because data is already present on the bus, bear in mind that some bytes will be altered prior to transmission. Bytes that will remain the same could actually be transmitted without being read into the PIC processor first, but it is advisable to use a standard routine that has all bytes read from the UART and then output from the PIC processor. The outputs of the UART are set to the high impedance state by taking the Receiver Register Disable (RRD) input high. The PIC processor then switches its eight-bit port to the output mode, writes the appropriate data to the port, and then pulses the Transmitter Buffer Register Load (TBRL) input of the UART low. Next the eight-bit port of the PIC processor is returned to the input mode, and then the RRD input of the UART is returned to the low state. This takes things back to the beginning, and the PIC processor then monitors the DR output of the UART until the next byte of data is received. The whole process is then repeated for the next and subsequent bytes of data.

For some types of processing this arrangement is all that is needed. In others it is necessary for the user to input information to control the way in which the data is processed. The pitch-bend filter is an example of an application in which the user does not have to supply any information. The MIDI processor simply removes all pitch-bend messages and passes all others through to output unaltered.

Things are different in the case of the harmoniser. The unit could simply raise of lower the pitch of all note messages by a predetermined amount, but this arrangement clearly lacks versatility. It is better if the PIC processor monitors switches that enable the user to alter the amount and direction of the shift in pitch. And eight-bit input of the processor is available for this purpose, and on the prototype this monitors two hex switches. Where necessary these can be replaced by other types of switch, or simply omitted altogether. This aspect of the design has to be tailored to suit your particular application.

Circuit operation

The main circuit diagram for the MIDI processor appears in **figure 2**. IC3 is the UART, and it can be used with any normal serial data word format. The standard word format for MIDI interfaces is one start bit, eight data bits, one stop bit, and no parity checking. Setting the required word format is just a matter of taking pins 35 to 39 to the appropriate logic levels and taking pin 34 high so that this information is loaded into the appropriate register of the UART. The clock oscillator uses transistor Q2 in a

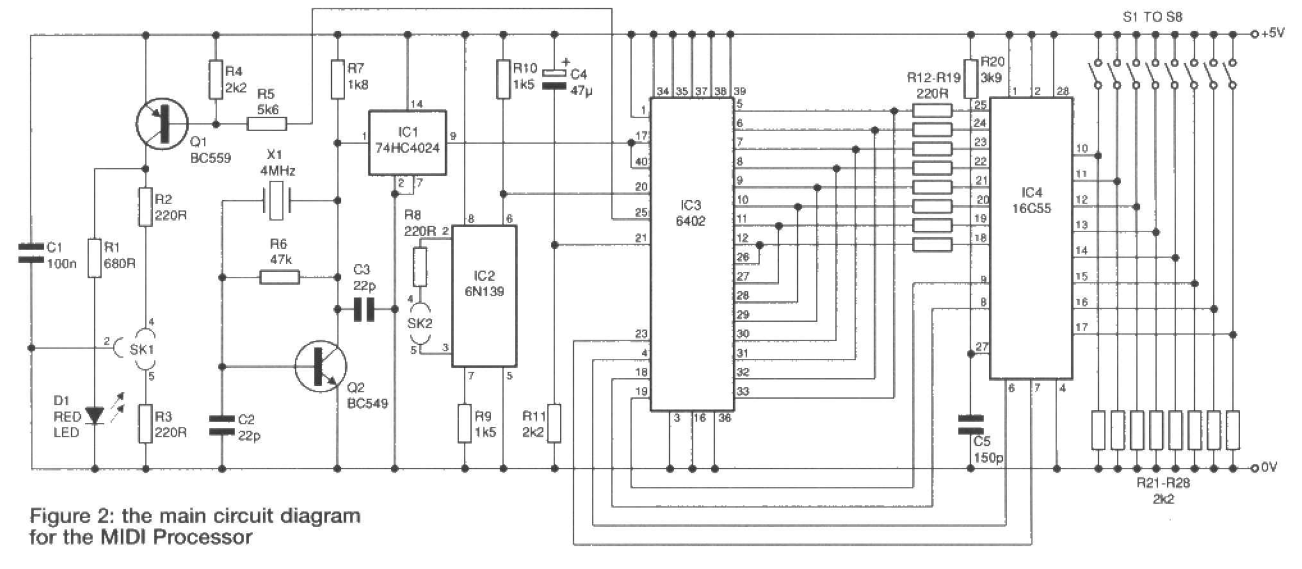


Figure 2: the main circuit diagram for the MIDI Processor

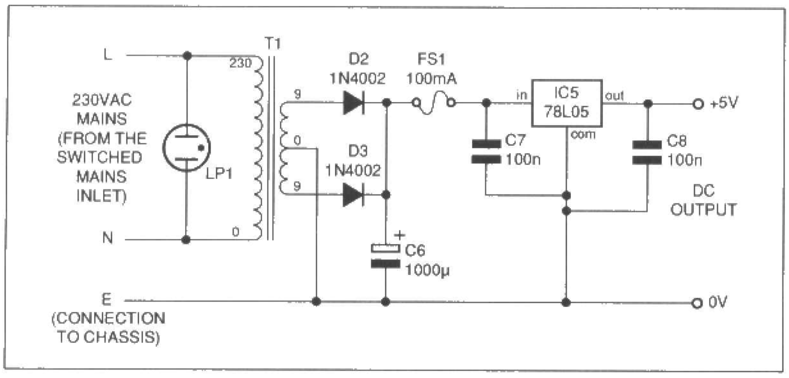


Figure 3: the circuit diagram for the mains power supply

conventional configuration. It drives IC1, which is a CMOS 4024 seven-stage binary counter, but in this application only the first three stages of IC1 are actually used. Note that an ordinary 4024 is not guaranteed to operate correctly at 4 MHz with a five-volt supply. Therefore, the high speed CMOS 74HC4024 must be used for IC1. The 6402 UART has separate clock inputs for the receiver and transmitter sections, but in this case they are driven in parallel because the reception and transmission baud rates are the same.

Opto-isolation at the MIDI input is provided by IC2, which is a high-speed device that has a photo-diode driving a common emitter switching transistor in the output section of the device. This provides suitably fast switching times, and the 6N139 can actually handle baud rates of up to about ten times the 31250 baud used for MIDI interfaces. Ordinarily opto-isolators are not fast enough for use in this circuit, and only the specified device should be used. At the MIDI output, transistor Q1 acts as a combined inverter and open collector output stage. Q1 must be switched on when the serial output of the UART goes low, and switched off when it goes high. Using an NPN output transistor would require the use of an inverter in order to obtain the required action, but by using a PNP transistor an output signal of the correct polarity is obtained without the aid of an inverter stage. D1 is an optional LED indicator that flashes when the unit outputs MIDI data. This is useful when initially testing the unit, and can also be useful when the device driven from the MIDI processor does not seem to be functioning correctly. If LED D1 flashes you know that the unit is actually transmitting MIDI data, and that the problem is a lack of response from the receiving device. In order to initialise correctly the UART must be provided with a long positive reset pulse at switch-on. This is provided by C4 and R11.

IC4 is the PIC processor, and this circuit will operate using either a 16C55 or a 16C57. The latter has more memory, but in other respects the two devices are identical. A simple CR clock oscillator is used and this has R20 and C5 as the timing components. Obviously IC4 must be a version of the 16C55 or 16C57 that supports this type of clock circuit. The clock frequency is typically a little over 1 MHz, which should be considerably more than adequate for most applications. However, if necessary the clock frequency can be boosted to about 4 MHz by reducing the value of C5 to 33p. Port A of IC4 is a four-bit type that is used here to control the UART. The following table details the method of connection used.

PIC Port	In/Out	UART
RA0	Output	RRD
RA1	Output	TBRL
RA2	Output	DRR
RA3	Input	DR

Port B is an eight-bit type that connects to the bidirectional data bus. It is connected to the UART by way of eight current limiting resistors that protect both the UART and the PIC processor if a programming error should result in

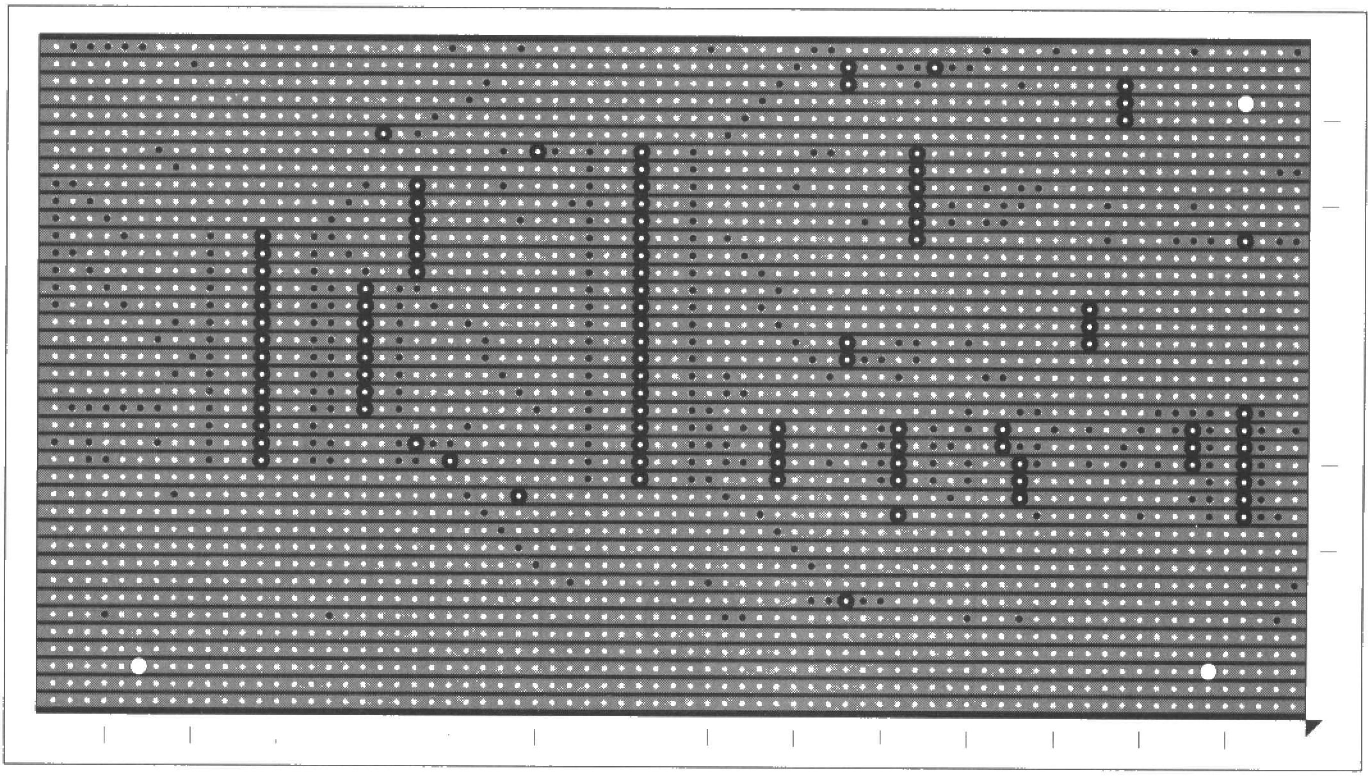


Figure 4: the underside view of the stripboard

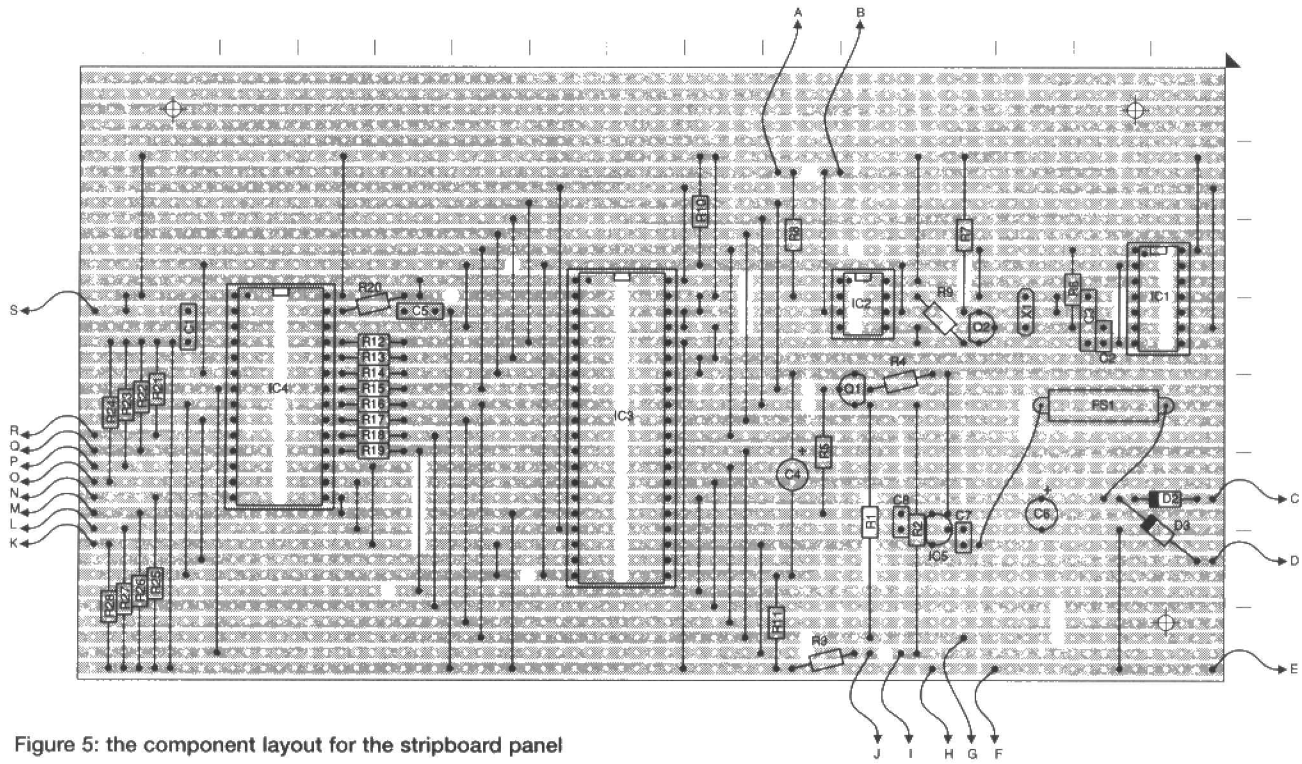


Figure 5: the component layout for the stripboard panel

both devices being set to the output mode simultaneously. If the unit is only used with tried and tested programs these resistors are not really necessary and the PIC processor can then be connected direct to UART. Port C of IC4 is used as eight inputs that read the two hex switches that enable the user to input information to the device. These inputs are normally held low by pull-down resistors R21 to R28, but closing one of the input switches (SW1 to SW8) results in the appropriate input being taken high.

The current consumption of the circuit varies from around 10 to 25 milliamps depending on the states of the input switches. A reasonably accurate and stable 5V supply is required. The simple mains power supply circuit of **figure 3** is more than adequate to power the unit, and should in fact be capable of powering to of three MIDI processor circuits if required. It is a conventional full-wave design using monolithic voltage regulator IC5 to provide a well smoothed and regulated output. IC5 has built in output current limiting, but additional protection against overloads his provided by fuse FS1.

Construction

The main circuit and the power supply are built on a stripboard which measures 73 holes by 39 copper strips. This can be a length cut from a standard 300 by 100 mm stripboard. Details of the numerous breaks in the copper strips on the underside of the board are provided in **figure 4**. The three mounting holes in the board are about 3.3 mm in diameter and will accept either 6BA or metric M3 mounting bolts. **Figure 5** shows the component layout for the board. **Mains circuits can be dangerous if not correctly constructed. If you are not experienced in mains construction, seek the advice of someone who has the necessary experience.**

IC1, IC3, and IC4 are all CMOS devices that require the normal anti-static handling precautions. As neither the PIC processor nor the UART are cheap it is advisable to be particularly careful when dealing with these components. A large number of link-wires are required, and these are made from 24 swg (0.56 mm) tinned copper wire. Where long link-wires run side-by-side it is advisable to insulate them with

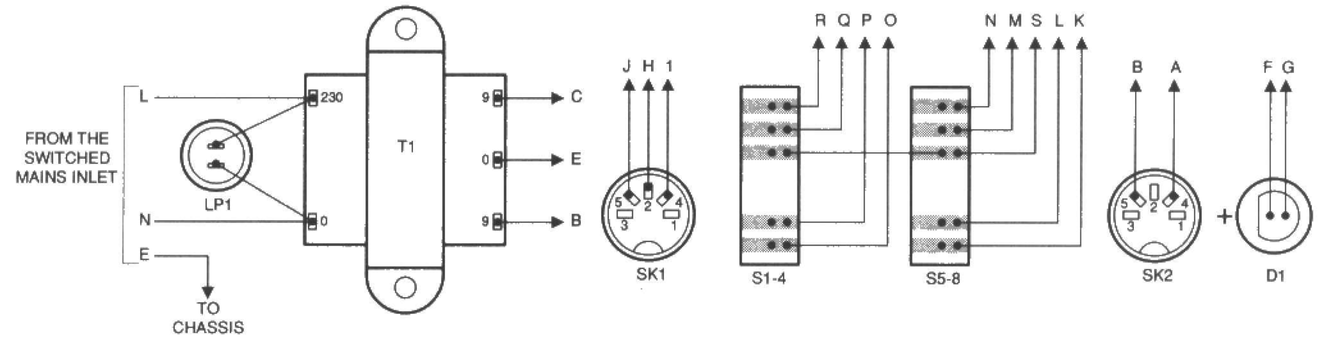


Figure 6: details of the hard wiring

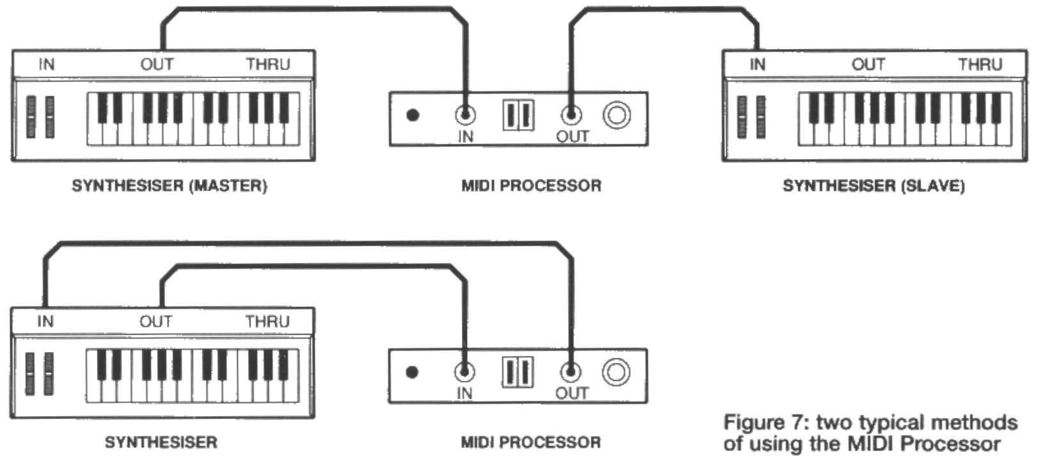


Figure 7: two typical methods of using the MIDI Processor

pieces of PVC sleeving so that accidental short circuits are avoided. Be careful not to omit any of the link-wires, especially the shorter ones that are easily overlooked. Fuse FS1 is mounted on the circuit board via a chassis mounting fuse holder. The holder is bolted to the board using a short 6BA or M3 screw and fixing nut, which are not normally supplied with the holder. The fuse holder is then hard wired to the appropriate two points on the circuit board. Crystal X1 must be a miniature wire-ended type having 5 mm (0.2 in) lead spacing if it is to fit easily into this component layout. There is little space available for the non-electrolytic capacitors, which must therefore be miniature ceramic types. Make quite sure that rectifiers D2 and D3 are connected the right way round and that the breaks in the copper strips which isolate the power supply circuit from the UART are all present and correct. Mistakes here could prove to be costly.

The prototype MIDI processor is housed in a 19-in rack-mount case. This type of case was used because the prototype was designed to fit in with other rack-mount equipment, and a much smaller case will actually suffice. **Because the unit is mains powered it essential to house it in a metal case that must be reliably earthed to the mains earth lead. Also, the case must be a type that has a screw fitting lid or cover so that there is no easy means of gaining access to the dangerous mains wiring.**

The mains input should be via a 200mA slow blow fuse, and all mains connections should be properly insulated. This is not shown in the photograph of the internal wiring, because this photograph was taken with temporary wiring in place to test the unit.

The recommended method to feed in the mains is to use a filtered IEC mains inlet, with switch and fuse. This avoids the need for extra wiring and insulation for the fuse and mains switch. If an IEC inlet is used, the ground wire should be soldered to the ground terminal of the inlet, and bolted directly to the metalwork, even if the live and neutral connections are via crimp connectors.

If a captive mains lead is to be used, it should be run via a strain relief grommet.

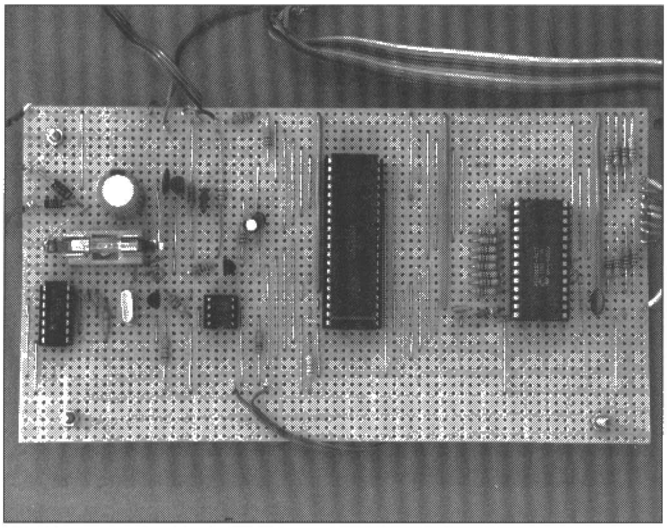
Details of the hard wiring are provided in figure 6, which should be used in conjunction with **Figure 5** (point A in Figure 5 connects to point A in **Figure 6**, point B connects to point B, and so on).

The wiring to switches SW1-SW8 must obviously be varied to suit the particular switches you are using, if any are fitted at all. No switches are needed if the unit is used with the pitch-bend filtering program. When used with the harmoniser program a hex switch is needed for SW1 to SW4, and this sets the amount by which the pitch is shifted. SW5 can be a miniature toggle switch, with SW6 to SW7 then being omitted. The pitch is shifted upwards when SW5 is closed and downwards when it is open. If a hex switch is used for SW5 to SW8, odd numbers produce an upwards shift, and even numbers (including 0) produce downwards movement. The two hex switches used on the prototype do not have the usual tags or pins, but instead have what can only be described as small printed circuit boards. In common with most switches of this type, one connection is common to all four switches. Note that the switches must be of a type that uses ON to represent logic 1 and OFF to represent logic 0. Pin two of SK1 connects to the screen of the MIDI connecting cable, and to the earth rail of the MIDI processor. Pin 2 of SK2 must not be connected to the earth rail of the processor as this would circumvent the opto-isolation at the input of the unit.

In use

The MIDI processor is connected into the MIDI system using standard MIDI leads. When initially testing the unit, connect its input socket to the output of a MIDI keyboard or keyboard instruments, and play some notes. If all is well there should be some flashing from output indicator D1, although it will not light up very brightly unless there is plenty of activity on the unit's output.

The way in which the processor is connected into the system will obviously depend on the function it provides, and the exact way in which you wish to use it. **Figure 7** illustrates two basic methods of using the unit. In the **two-synthesiser system** the processor is used to doctor the signal from the master instrument before it is fed to the slave synthesiser. This setup could be used with the processor providing either MIDI pitch-bend filtering or a harmoniser action. If it is used to provide filtering, the master instrument will respond to pitch wheel adjustments but the slave instrument will not. Operating the pitch wheel of the master synthesiser should not produce any activity on the output indicator (D1). With the processor providing a harmoniser action the slave instrument should follow the master synthesiser, but with the notes changed by the appropriate number of semitones. In the **single synthesiser setup** any form of MIDI filtering is unlikely to do anything useful. With processing such as harmonising, the instrument should play the doctored notes received via its MIDI input socket in addition to those played on the keyboard. However, with some instruments (particularly older types) there may be some limitations on simultaneous use of the keyboard and the MIDI input, and this setup cannot be guaranteed to operate properly with all instruments.



Software

The pitch-bend filtering program (**listing 1**) is the more simple of the two, and is the one I will consider first. The initial part of the program sets RA0/1/2 as outputs but leaves RA3 as an input. It also sets RA0/1/2 with the correct initial output states. Next the main program loop is entered, and here the DR flag of the UART is repeatedly monitored until a fresh byte of data is ready and RA3 is taken high. A pulse is then generated on RA2, and this clears the DR flag. The program must then check to determine whether the byte of data is a status byte in a pitch-bend message. The lower nibble of a status byte contains the channel number, which is information we do not require in this case, as the unit must remove pitch-bend messages on any channel. The lower nibble is therefore masked using a bitwise AND instruction and a masking value of 0F. Next the byte is exclusive ORed with a value of E0, and this returns a value of zero only if the message is a pitch-bend type, and the upper nibble is E (1110 binary). If the value produced is zero, the program branches to the subprogram ATRANS2". Here two further bytes of data are read from the UART, after which the program returns to the beginning of the main loop. This results in all three bytes of the pitch-bend message being read from the UART, but none of them being transmitted, and the required filtering is therefore obtained. If the XOR instruction produces a result that is other than zero, the program continues along the main loop, with the byte of data being transmitted prior to the program returning to the beginning of the main loop.

The harmoniser program (**listing 2**) has some similarities to the filter program, but in the XOR instruction a value of 90 is used, followed by a figure or 80 in a subsequent XOR instruction. These instructions are used to detect note-on and note-off messages respectively. If neither of the messages is detected, the program continues around the main loop, transmitting the received byte of data on the way. If either type of message is detected, the program branches to the subprogram called ATRANS2". This transmits the byte of data just received, and then waits for the next byte which will be the data byte containing the note value. When this byte is received, the switches that supply the pitch shift value are read, and this value is then added to or subtracted from the data byte, depending on the setting of SW5. The modified data byte is then transmitted, after which the program returns to the beginning of the main program loop.

- MIDI control by PIC programming makes for flexibility
- Harmoniser and pitch bend filter sample programs
- Can be used in a master/slave configuration, or with many single machines
- Serial/parallel and parallel/serial is handled by UART to simplify the function programming
- Opto-isolation at the input of the receiving device helps avoid problems with hum and earth loops, and also helps to prevent digital noise
- Power supply circuit is included on the stripboard layout

The program has no error trapping to prevent the modified data byte cycling though zero, or going above EF. In most cases this is not necessary anyway, because the master instrument will not be able to get within 15 semitones of the maximum and minimum valid MIDI note values. Where necessary, you must be careful to stay within the limits of the system. MIDI permits one note-on or note-off header byte to be followed by several pairs of data bytes. This system is apparently used more by sequencers than by MIDI instruments, and is not used by any of my MIDI equipment. The harmoniser program would require modification in order to operate with equipment that does use this method of handling notes.

Listing 1: the Midi Pitch Bend Filter Program

```
;****************************************
;MIDI PITCH BEND FILTER PROGRAM
;****************************************
;
STATUS      EQU         03
PORTA       EQU         05
PORTB       EQU         06
PORT        EQU         07
STORE1      EQU         0D
STORE2      EQU         0E
            MOVLW       08
            TRIS        PORTA       ;Sets RA0/1/2 as outputs
            MOVLW       06
            MOVWF       PORTA       ;Sets initial control
                                    line states
START       BTFSS       PORTA,3
            GOTO        START       ;Waits for data to be
                                    received
            BCF                     PORTA,2
            NOP
            NOP
            NOP
            BSF         PORTA,2     ;Clears UART's DR FLAGS
            MOVF        PORTC,0     ;Loads data into W
            ANDLW       0xF0        ;Masks channel number
                                    (lower nibble)
            BCF         STATUS,2
            XORLW       0xE0        ;Detect Note on header
            BTFSC       STATUS,2
            GOTO        TRANS2
;
            MOVF        PORTC,0     ;Reads UART into W
            MOVWF       STORE2      ;Stores value from UART
            BSF         PORTA,0     ;Switches off UART
                                    outputs
            CLRW
            TRIS        PORTC       ;Sets Port C as outputs
            MOVF        STORE2,0    ;Loads transmit data
                                    into W
            MOVWF       PORTC       ;Loads data into Port C
            BCF         PORTA,1
            NOP
            NOP
            NOP
            BSF         PORTA,1     ;Loads data into UART's
                                    transmit buffer
            MOVLW       0xFF
            TRIS        PORTC       ;Sets Port C as inputs
            BCF         PORTA,0     ;Switches on UART
                                      outputs
            GOTO        START
;
TRANS2      BTFSS       PORTA,3
            GOTO        TRANS2      ;Waits for data to be
                                    received
            BCF        PORTA,2
            NOP
            NOP
            NOP
            BSF        PORTA,2     ;Clears UART's DR FLAGS
LOOP        BTFSS      PORTA,3
            GOTO       LOOP        ;Waits for data to be
                                   received
            BCF        PORTA,2
            NOP
            NOP
            NOP
            BSF        PORTA,2     ;Clears UART's DR FLAGS
            GOTO       START
            END
```

Listing 2: the Midi Processor Program

```
;***********************************
;MIDI PROCESSOR PROGRAM
;***********************************
;
STATUS      EQU                    03
PORTA       EQU                    05
PORTB       EQU                    06
PORTC       EQU                    07
STORE1      EQU                    0D
STORE2      EQU                    0E
            MOVLW      08
            TRIS       PORTA       ;Sets RA0/1/2 as
                                   outputs-RA3 as input
            MOVLW      06
            MOVWF      PORTA       ;Sets initial control
                                   line states
START       BTFSS      PORTA,3
            GOTO       START       ;Waits for data to be
                                   received
            BCF        PORTA,2
            NOP
            NOP
            NOP
            BSF        PORTA,2     ;Clears UART's DR Flag
            MOVF       PORTC,0     ;Loads data into W
            ANDLW      0xF0        ;Masks channel number
                                   (lower nibble)
            BCF        STATUS,2
            XORLW      90          ;Detect Note on header
            BTFSC      STATUS,2
            GOTO       TRANS2
            MOVF       PORTC,0
            ANDLW      0xF0
            BCF        STATUS,2
            XORLW      80          ;Detect note off header
            BTFSC      STATUS,2
            GOTO       TRANS2
;
            MOVF       PORTC,0     ;Reads UART into W
            MOVWF      STORE2      ;Stores value from UART
            BSF        PORTA,0     ;Switches off UART
                                   outputs
            CLRW
            TRIS       PORTC       ;Sets Port C as outputs
            MOVF       STORE2,0    ;Loads transmit data
                                   into W
            MOVWF      PORTC       ;Loads data into Port C
            BCF        PORTA,1
            NOP
            NOP
            NOP
            BSF        PORTA,1     ;Loads data into UART's
                                   transmit buffer
            MOVLW      0xFF
            TRIS       PORTC       ;Sets Port C as inputs
            BCF        PORTA,0     ;Switches on UART
                                    outputs
            GOTO       START
;
TRANS2      MOVF       PORTC,0     ;Reads UART into W
            MOVWF      STORE2      ;Stores value from UART
            BSF        PORTA,0     ;Switches off UART
                                    outputs
            CLRW
            TRIS       PORTC       ;Sets Port C as outputs
            MOVF       STORE2,0    ;Loads transmit data
                                    into W
            MOVWF      PORTC       ;Loads data into Port C
            BCF        PORTA,1
            NOP
            NOP
            NOP
            BSF        PORTA,1     ;Loads data into UART's
                                   transmit buffer
            MOVLW      0xFF
            TRIS       PORTC       ;Sets Port C as inputs
            BCF        PORTA,0     ;Switches on UART
                                   outputs
LOOP        BTFSS                  PORTA,3
            GOTO       LOOP        ;Waits for data to be
                                   received
            BCF        PORTA,2
            NOP
            NOP
            NOP
            BSF        PORTA,2     ;Clears UART's DR Flag
            MOVF       PORTB,0
            ANDLW      0F
            MOVWF      STORE1      ;Reads and stores offset
                                   switch value
            MOVF       PORTC,0     ;Reads UART into W
            MOVWF      STORE2      ;Stores note data
            MOVF       STORE1,0
            BTFSC      PORTB,4
            ADDWF      STORE2,1    ;Adds value read from
                                   switches to data
            BTFSS      PORTB,4
            SUBWF      STORE2,1    ;Or subtracts value read
                                   from switches
            BSF        PORTA,0     ;Switches off UART
                                    outputs
            CLRW
            TRIS       PORTC       ;Sets Port C as outputs
            MOVF       STORE2,0    ;Loads transmit data
                                    into W
            MOVWF      PORTC       ;Loads data into Port C
            BCF        PORTA,1
            NOP
            NOP
            NOP
            BSF        PORTA,1     ;Loads data into UART's
                                   transmit buffer
            MOVLW      0xFF
            TRIS       PORTC       ;Sets Port C as inputs
            BCF        PORTA,0     ;Switches on UART
                                    outputs
            GOTO       START
;
            END
```

PARTS LIST for the MIDI Processor

Resistors

(5 percent 0.25W carbon film)

R1	820R
R2,3,8,12 -19	220R
R4,11,21 - 28	2k2
R5	5k6
R6	470k
R7	1k8
R9,10	1k5
R20	3k9

Capacitors

C1,7,8	100n ceramic
C2,3	22p ceramic plate
C4	47u 25V radial elect
C5	150p ceramic plate
C6	1000u 25V radial elect

Semiconductors

IC1	74HC4024
IC2	6N139 opto-isolator
IC3	6402 UART
IC4	PIC 16C55 or 16C57
IC5	78L05 +5V 100mA regulator
D1	Red panel LED
D2, 3	1N4002 100V 1A rectifier
Q1	BC559
Q2	BC549

Miscellaneous

X1	4-MHz wire-ended crystal
SW1-SW8	Dual hex switch (see text)
SW9	Rotary mains switch
SK1, 2	5-way 180-degree panel mounting DIN socket
LP1	Mains panel neon indicator
T1	Standard mains primary, 9-0-9 volt secondary rated at 100mA or more
FS1	100mA "quick-blow" fuse

Metal case, 0.1-inch stripboard 73 holes by 39 strips, 8-pin dil holders, 14-pin dil holder, 28-pin dil holder, 40-pin dil holder, chassis mounting 20mm fuse-holder, control knob, mains plug with 2A fuse and lead, IEC mains inlet, 20mm 200mA T fuse, wire, solder, etc.

Circuits for Music Lovers

James Scott

Presence for singers, two Waa-waa circuits for guitarists, and the "Ricky Sound" to build.

The day comes when your plain, unvarnished guitar sound no longer vibrates your creative nerve. What do you do about that? Well, if you are like me (and most of our friends) you get a more powerful amp and a couple of distortion pedals and go for the mega-rippup sound for an eon or two.

So what do you do when shattering the mirror no longer entirely fulfils your creative urge? Look for something new - or something old. A small amount of tone processing can do wonders for a good guitar sound, and the two sounds in this article, Waa-waa and "Ricky" (for Rickenbacker), hark back to the classic period on the 60s and 70s when the Byrds and Jimi had just pitched onto the scene.

The presence circuit for singers is not an "effect" as such but it will bring the singer's voice forward in the mix. Why have a singer no-one can hear? You might as well get a trombone player instead!

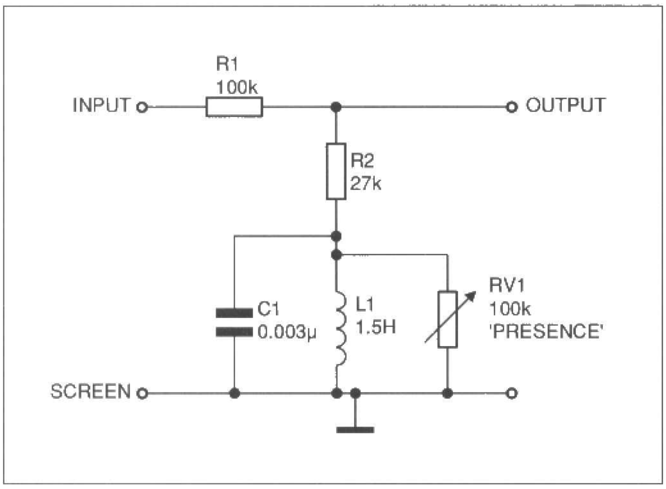


Figure 1: the circuit of the passive Presence Control

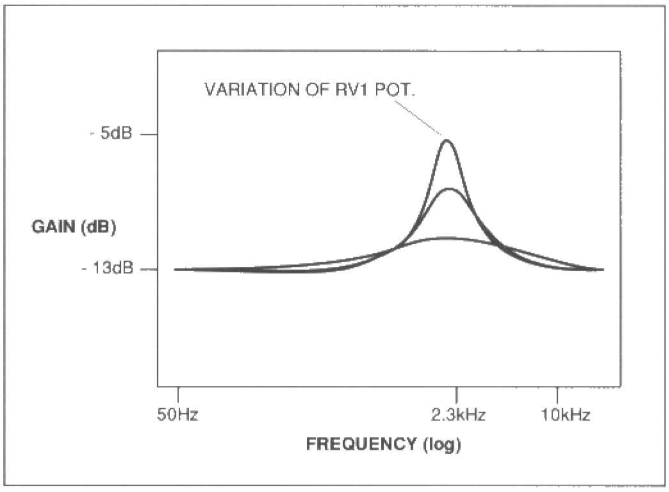


Figure 2: the Bode plot showing the increase in Q factor

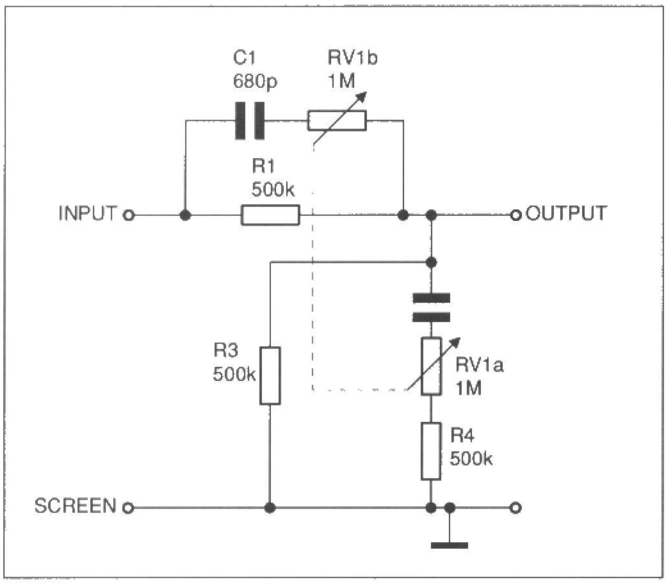


Figure 3: the Presence Control using ganged pots

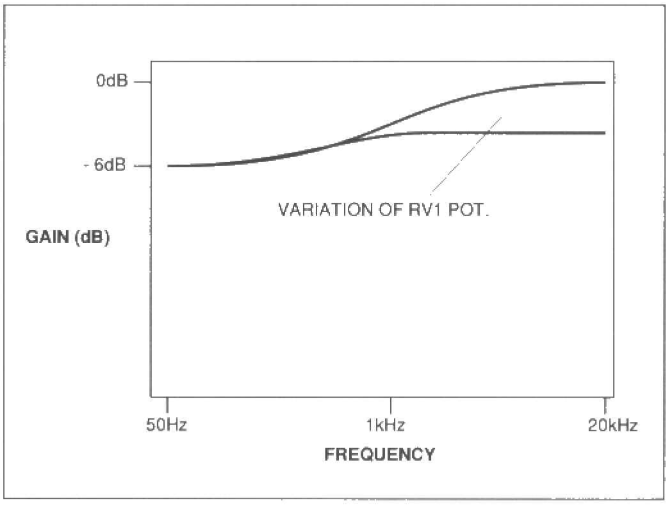


Figure 4: the Bode plot of the ganged pot Presence Control

What is presence?

Owning one of those low-bucks microphones usually makes the vocalist sound like someone singing through a feather pillow.

By using the circuit in **figure 1**, which incidentally has only five components, you will not improve the dynamic range, but you will certainly boost the voice frequencies without affecting the bass and treble accompaniment.

The circuit is quite unusual, as it uses a 1.5-henry coil. The output is actually a potential divider determined by the ratio of R1 to the sum of R2 and the total impedance of Zc1, ZL1 and RV1 or, if you prefer:

$$\text{Output} = \frac{\text{input} \times R2.}{R2 + (Zc1//ZL1//RV1)}$$

Where // means 'parallel with'

$ZL1 = 2\pi f.L1$

$Zc1 = 1/2\pi f.c1$

The Bode plot in **figure 2** explains the effect. By varying the pot RV1 from minimum to maximum, you increase the vocal presence Q factor. Try it!

When to use it

If this old-fashioned circuit is used for mixing you will be surprised how it makes a singer stand out while keeping the rest of the backing band in the background. Due to its simplicity, you can build it onto a piece of solder stripboard and put it into a metal box with two jack plugs, input and output. If it is not being used for mixing, but live performance, put the mic straight in and compensate for the attenuation with your pre-amp or combo settings. It is best used with a simple pre-amp stage.

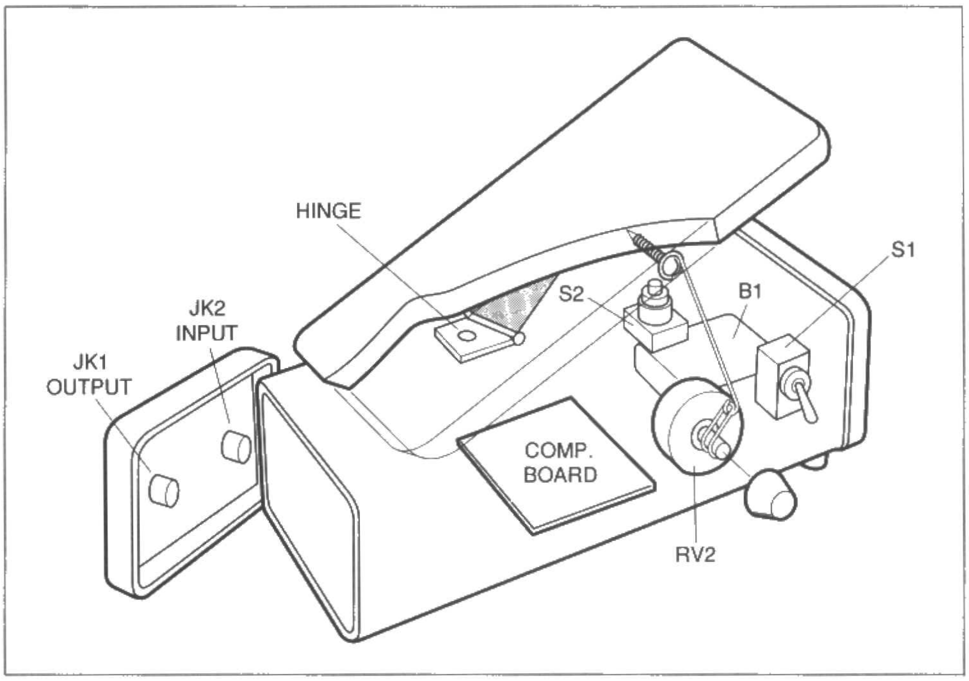


Figure 5: an internal layout for the Waa Waa in a traditional pedal housing

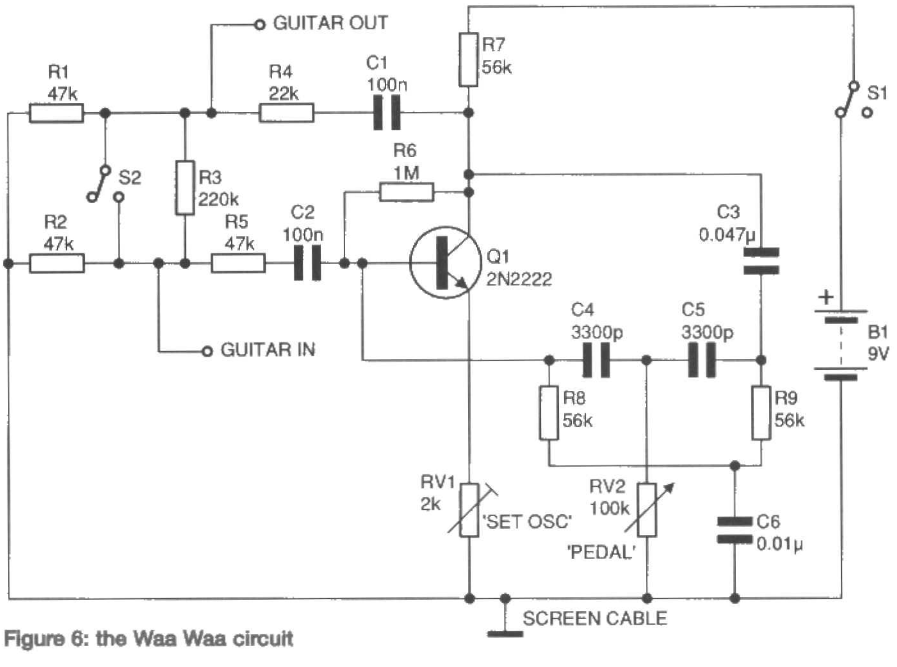


Figure 6: the Waa Waa circuit

That singer again

Another presence control?

Unlike the presence enhancer at the beginning of this article, which pin-points a narrow frequency band and dramatically boosts the selected range, this design (**figure 3**) provides a variable increase in accentuation of voice frequencies around 1kHz and above about 6 dB.

As with the previous design, it can be used to bring out the voice of a singer while keeping the orchestral accompaniment in the background.

At its maximum setting, a vocalist sounds about half as far away as with no accentuation. This potential divider is slightly more involved than the last design, due to the nature of the parallel and serial components around the ganged pots (**figure 4**)

The formula is:

$$\text{Output} = \frac{\text{Input} \times (Zc2+RV1a+R4)//R3.}{(Zc1 + RV1b//R1 + (Zc2+RV1a+R4)//R3}$$

Voodoo chile?

A One-transistor Waa-Waa unit

To be truthful, this is not exactly the same one that Jimi played, but the following three circuits come in second place, because all Waa-Waas work on the same principle.

The Waa-Waa is a selective amplifier not unlike a tone booster but with one main difference - that the selected frequency band can be moved up and down the frequency

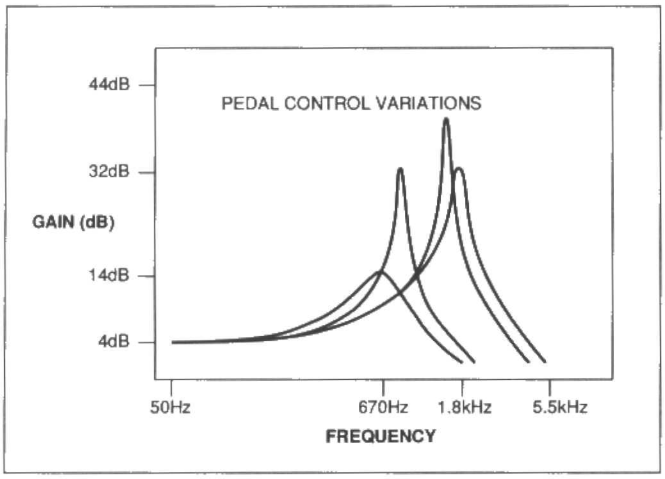


Figure 7: mid-frequency Bode plot for the Waa Waa

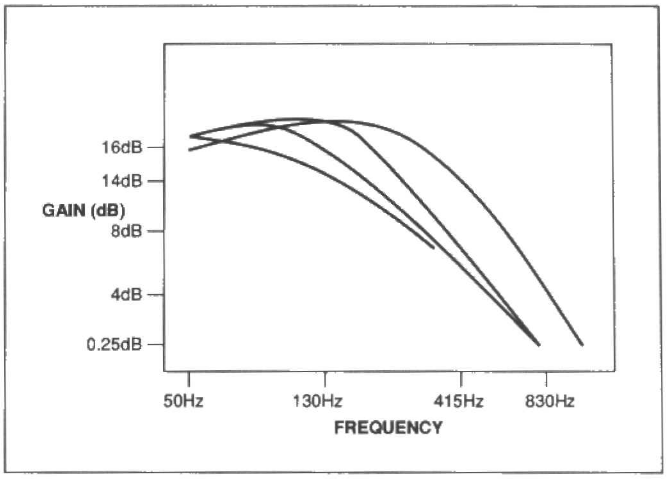


Figure 9: the Waa Growler Bode plot

range by operation of the foot pedal. The mechanics of the footpedal is at least as important as the electronics (**figure 5**), which is very simple indeed.

All the following designs are variations on a theme, namely a phase shift oscillator. Normally, due to positive feedback, the circuit will oscillate at the resonant frequency chosen by a twin T network of two capacitors and resistor or two resistors and a capacitor; look at the first design in **figure 6**, which incidentally fits into the type of box shown in **figure 5**. The circuit is tuned with RV1 to the point just before a whistling oscillation starts. The natural frequency can now be varied by changing RV2 via the foot pedal. This effect can be second on the Bode plot in **figure 7**. The natural frequency is determined by C4 and C5. The Waa effect is most pronounced between 1kHz to 2kHz in the mid-range. Since we are feeding the guitar directly into a high gain oscillator, it is sometimes necessary to have a buffer network as shown by R1, R2, R3, R4 and R5. When building this unit, try to get a high gain npn transistor such as a BC109C or a 2N2926 green spot. These will give the most effect. I simulated this circuit using a 2N2222, which worked well.

A note about the box: if you take care and have a rigid container and an older type brass pot, you can get very good results. I made this mechanism in 1969 after I heard Electric Ladyland, and it has stood the test of time ever since.

The waa growler

Low frequency waa-waa

In the design in **figure 8**, the phase shift oscillator based on C4 and C5 are non-symmetrical and calculated to ring at a much lower frequency, about 130Hz, as you can see from the bode plot (**figure 9**). This is very effective for bass lines. Feel free to experiment slightly with the symmetry and values of the capacitors if you want a more peaky response. When setting up, make sure that RV1 is amplifying rather than oscillating.

Figure 10 shows an alternative box design using a linear pot connected and damped to the foot pedal.

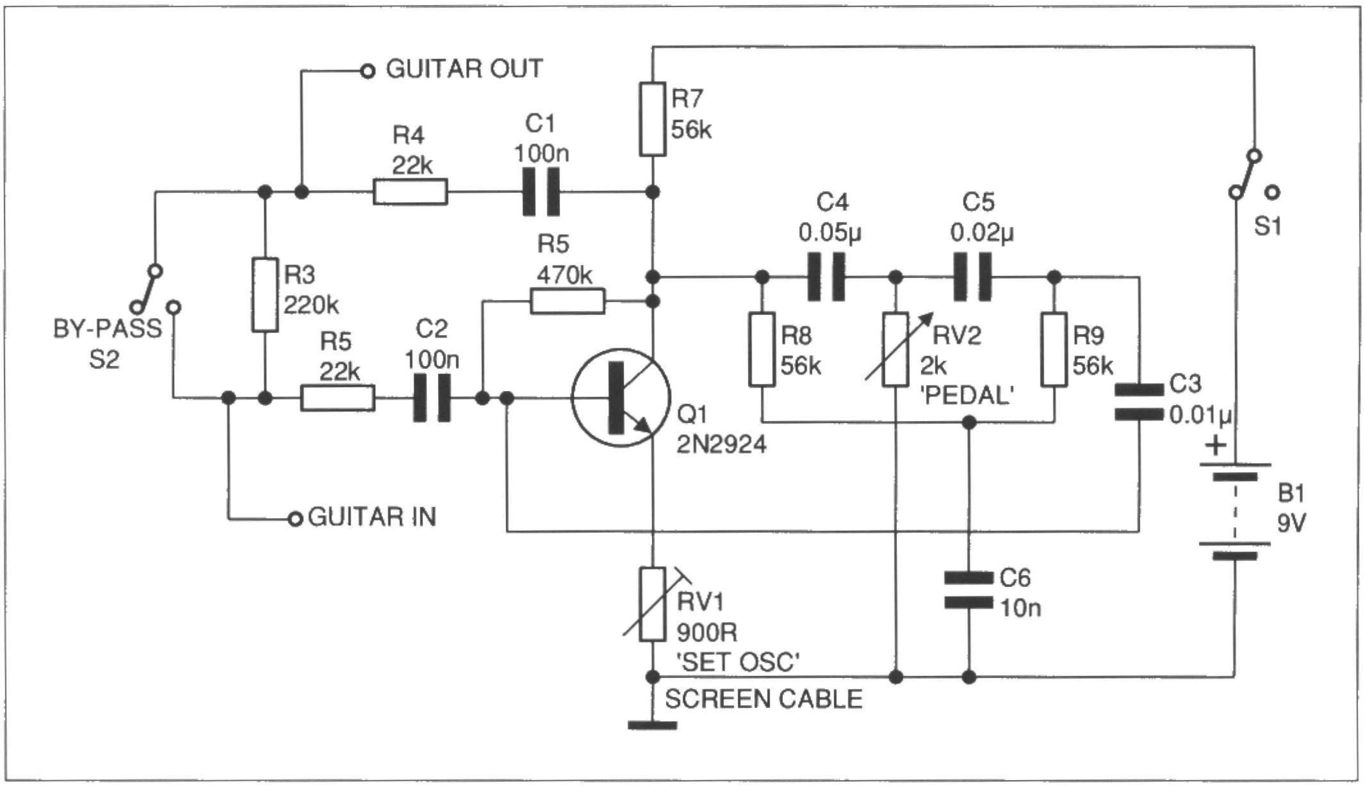
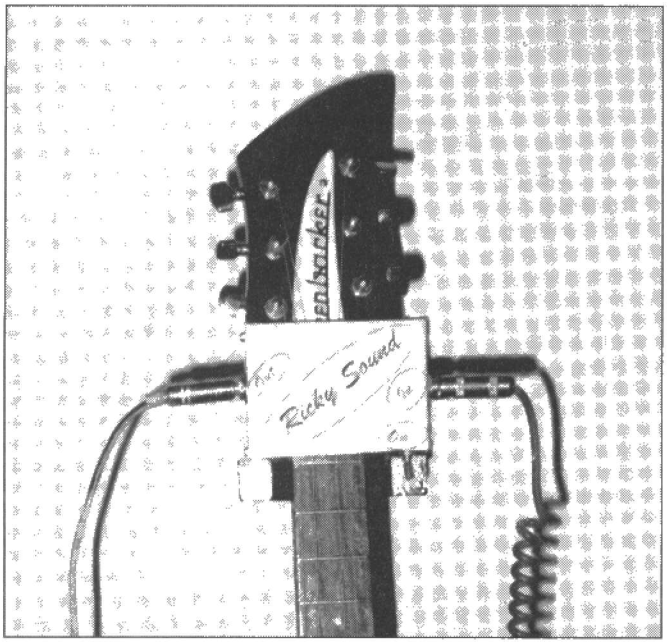


Figure 8: the Waa Growler circuit



The Ricky Sound

An active tone booster

Do your pickups lack bite and only give you a muddy output? Are you trying to get that old-fashioned crispy sound like the Byrds? This little gem could help you by emphasising some of the higher-order harmonics without attenuating the bass. It enriches the treble harmonics within the spectrum of 1kHz to 10kHz, peaking at 5kHz with a gain of 25dBs and - here's the important bit - without distortion.

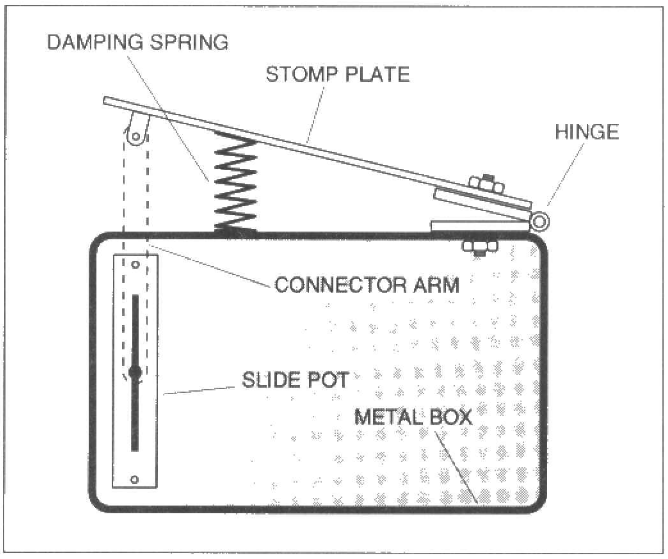


Figure 10: an alternative casing design using a linear pot

At the bass frequencies between 50Hz and 1kHz the original tone and gain remains relatively unaffected. The Bode plot depicts this phenomenon quite clearly.

To my ears, a low-quality pickup put through this miniature box sounds not unlike my 325 Rickenbaker.

How it works

The circuit (**figure 11**) is a two-transistor complementary amp, with a T-bridge formed by R4, R5, C3 and C2 feeding back from Q2 to Q1. The lower the feedback impedance the higher the gain. The peak frequency f is determined by the formula in **figure 12**. C4 gives negative feedback to S2. Resistors R1 and R2 bias the transistors for a correct dc operating point from

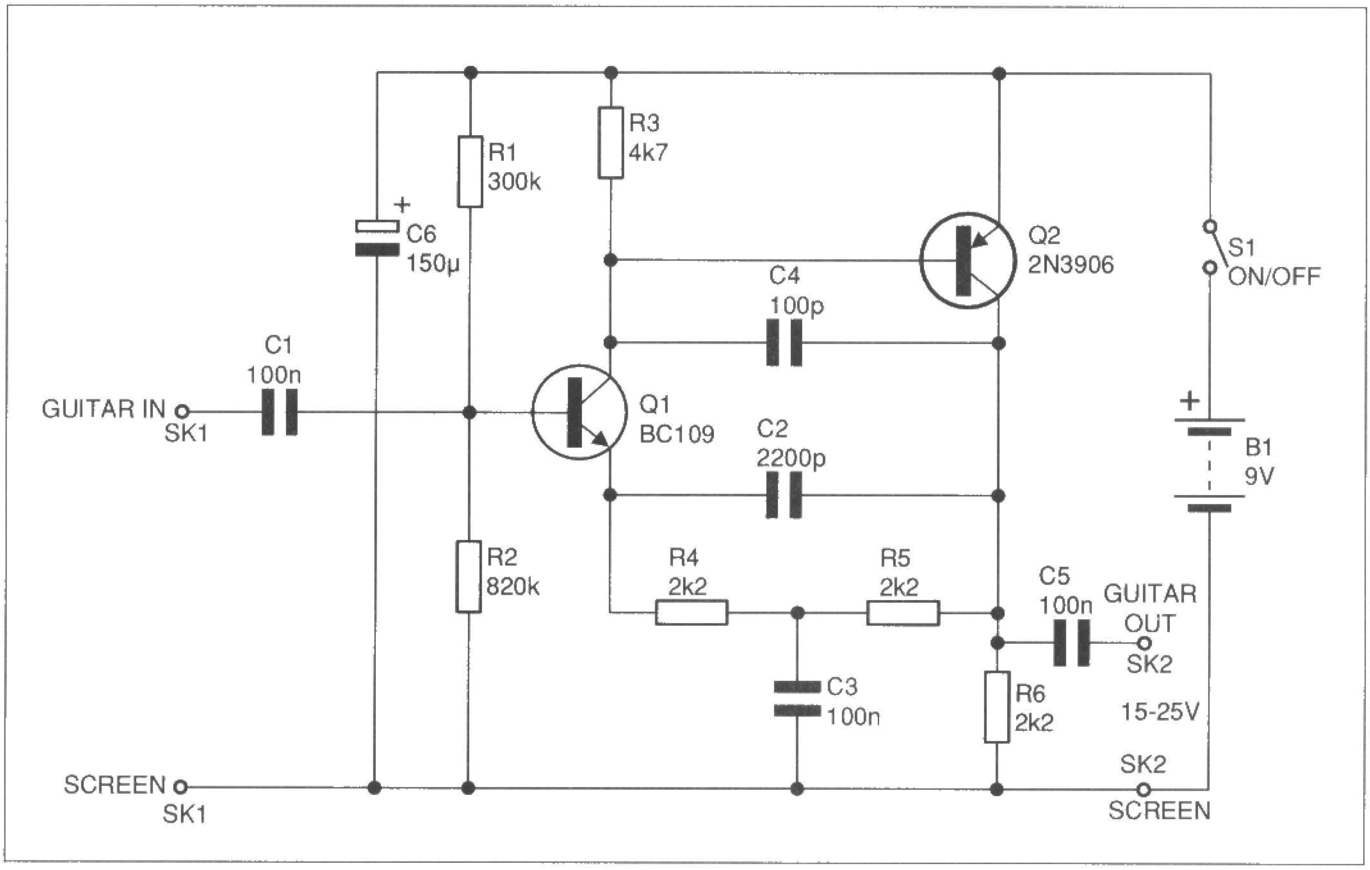


Figure 11: the Ricky Sound Simulator circuit

$$f = \frac{1}{2\pi\sqrt{R_4R_5C_2C_3}}$$

Figure 12: peak frequency formula

the 9V battery. Capacitor C6 smooths the circuit from any voltage blips. C1 and C5 together decouple the unit from your guitar and the amplifier that you are going to use. If you are using a bass guitar, reduce the value of C1 to 0.01 microfarads. This circuit has excellent dc stability and long battery life. Just about any small pnp and npn transistors with differing dc gains will work with this tone-enhancer, allowing you to achieve that vintage jangling sound. The Bode plot for the Ricky Sound is shown in **figure 13**. The component layout on my pcb is shown in **figure 14**, and a suggested final layout with box and 9V battery is shown in **figure 15**.

In the Parts List, note that the resistors are all 0.25 watt. The capacitors can be anything small that you can find (usually polyesters) and any range of small-signal high-gain npn and pnp transistors can be used. To save battery power, you can wire the battery switch via the switched jack plug terminal, where the earth contact is normally open, and the signal contact is normally closed.

In the next issue to ETI we will have a Bass/Treble boost and two smooth distortion circuits to complete the collection.

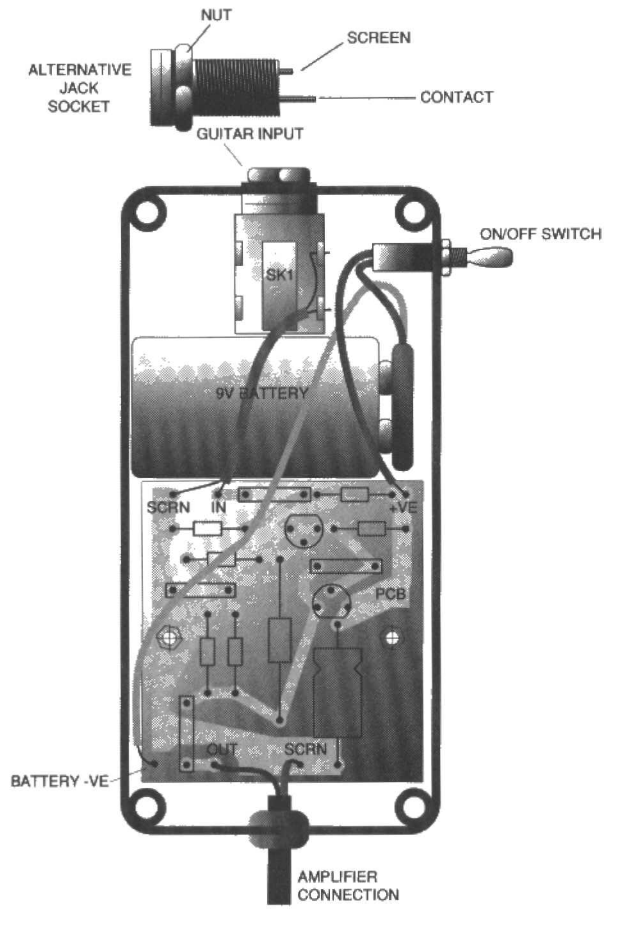


Figure 15: a case layout for the Ricky Sound. The author eventually decided to use a jack socket (shown at the top of the diagram) at the output

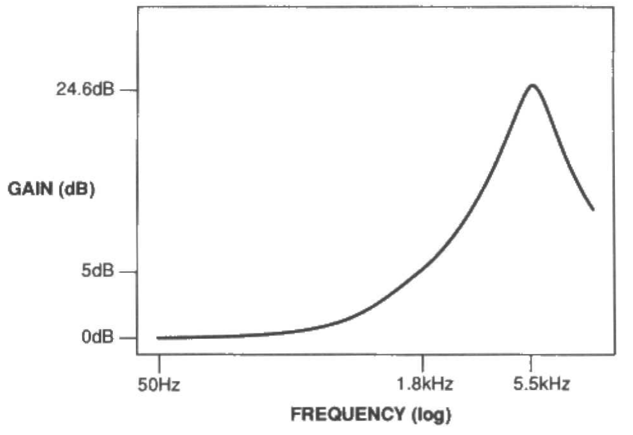


Figure 13: the Ricky Sound Bode plot

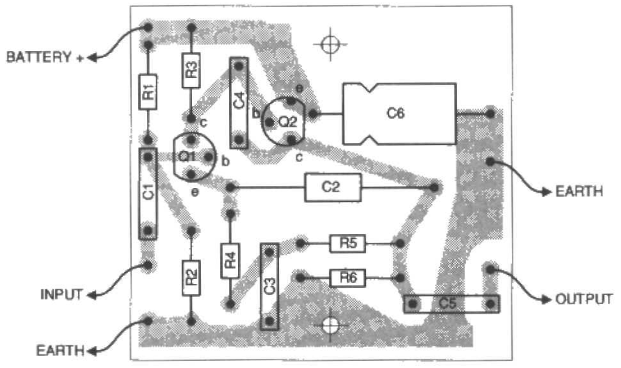


Figure 14: the Ricky Sound component layout

PARTS LIST *for the Ricky Sound*

Resistors

All 0.25 watt

R1	300k
R2	820k
R3	4.7k
R4, R5, R6	2.2k

Capacitors

C1,C3,C5	1n
C2	2200p
C4	100p
C6	150u electrolytic 15-25V (not critical)

Semiconductors

Q1	BC109C, ZTX384 or any good npn
Q2	2N3906, BC415P or any good pnp

Miscellaneous

SK1	jack socket

9V battery holder
9V battery
Box, pcb, solder, wire strain grommet etc.

PC Controllable 4-Line Dot Matrix Display

This month advice is given on choosing suitable power supplies for the system, and any changes required to the display panels and control board.

Robert Coward

This is the second part of three parts describing how to build a professional quality 24-character by 4-line dot matrix LED display system. In part 1 last month the various system components were described and detailed instructions were given on constructing the QUICC-IDM control board. This month covers suitable power supplies and any changes required to the display panels and control board. I then describe the various cable assemblies required, and how to connect up the system. By the end of it, you should be able to construct a fully working prototype system. Part 3 next month describes the making of a suitable enclosure, and assembling the system within it.

Logic supply

The logic supply needs to provide a minimum of 1A at 5V and 100mA at 24V, though significantly higher ratings would be desirable, so that the system can be expanded in the future. A supply providing 3A at 5Vand 500mA at 24V would be a reasonable choice.

When in standby, the system consumes typically 400mA at 5V, and 20mA at 24V, though these are only approximate figures. The chosen supply should ideally have no minimum load requirements on 24V, and less than 300mA on 5V. The regulation on the 24V supply is less critical than 5V, though it should not exceed 24V by more than 1V. The 5V supply should not deviate by more than 200mV or so.

Almost any type of fairly well regulated supply will suffice, but a switch mode supply is recommended to minimise power dissipation. Farnell Electronic Components sell a high quality Astec unit (part number 863-350), which would be perfectly suitable. Alternatively, you could design your own supply, possibly using a DC-DC converter to obtain the 5V supply efficiently, with a small liner regulator for the 24V supply. At time of writing Greenweld are selling a neat little Astec 5V 2A DC-DC Converter (part number Z660) for only £1.

The supply should ideally be convection cooled, as the system may be in standby for extended periods, and a continually running fan would be undesirable under such circumstances. Since the power consumption in standby mode is very low, any reasonably efficient supply should dissipate little heat in this mode. When the system is running, additional forced air-cooling will be provided by the main fan in the case (cooling is covered in more detail in part 3).

Main 8V display power supply

This supply is the most tricky to provide, as it needs to provide an unusual voltage at high current (around 15A continuous at 8V, though a higher rating of around 20A is desirable). This precludes the use of a linear supply, which would be too heavy and dissipate too much heat. Therefore, the only realistic option is a switch mode supply.

As the display's LED power consumption can vary from almost nothing (less than 50mA for a three-panel system) to over 15A with all LEDs lit, the supply should have no minimum load constraints. It must be able to cope with a rapidly and widely varying load, since the display may be rapidly changing, and have a significant number of flashing characters. In theory, the entire display could be flashed on and off at a rapid rate, and the supply should cope with this, but if it can't, at least it must shut down gracefully, without damaging itself or the display.

The supply needs to have some form of control input, so that it can be switched on and off via a logic control signal from the QUICC-IDM board. If this takes the form of an opto-isolated input, it can be fed directly from PL2 on the QUICC-IDM board. Alternatively, you could use the opto-isolated drive circuit on the board to drive a relay input, or switch the supply at the mains. More details are given later in this article.

Note that most supplies will have an integral fan, and ideally this should shut down when the supply is turned off via remote control. If the supply does not have its own fan, you may have to add one yourself, since the overall system cooling fan may not produce enough airflow for the PSU. If the fan is powered from the output, it will automatically stop when the supply is shut down **(most 12V fans will run happily from 8V, though at significantly reduced speed).**

The original supplies that came with the display system were large switch mode units, providing 8V at 75A each, and two were used to drive a 15-panel system, providing almost 100 percent surplus capacity. They have a simple control input that can be driven directly from PL2 on the QUICC-IDM board. Unfortunately, Greenweld had a few of these at the last count (part number X9122), but they have not been advertised for some time and you should check with Greenweld to ascertain availability. If you do obtain one of these units, check it over very thoroughly before use, as screws have known to work loose in these supplies. **The consequence of a supply of this capacity malfunctioning could be spectacular to say the least!**

Note that I do not recommend using a higher voltage supply such as 9V, unless it can be adjusted down to 8V, as the extra voltage will significantly increase the panel's power dissipation, and possibly cause damage. Alternatively, you could use high current rectifiers in series with each panel, but these will dissipate a lot of power at full load.

Using a 5V supply for the Display

You may find it almost impossible to obtain a suitable 8V supply because it is an unusual voltage, but the surplus market is flooded with high current 5V units, many of which are designed for PCs and other computer equipment. While these are not ideal, you may be able to adapt such a supply for use with the display system, though there will be some compromises.

The main issue is that 5V will result in a significantly dimmer display than 8V, for obvious reasons. The peak LED current will be halved, resulting in a corresponding drop in intensity. The reason for choosing 8V originally seems to have been to prevent excessive variation in brightness with supply voltage. This will get worse as the supply voltage nears the LED voltage, since the ballast resistors will need to be smaller. At 8V, the 39R ballast resistors give approximately 150mA peak current through each LED, driving it efficiently but wasting most of the power in the ballast resistors. At 5V, the peak current drops to 75mA, and the LED will run less efficiently, resulting in a brightness which is probably less than half that at 8V.

Unless you feel like changing every one of the 160 ballast resistors on each panel, you will probably have to live with the dimmer display. However, many supplies do have a voltage adjustment, **so if you crank this to maximum, you may be able to get out 6V or even more.** Remember that the supply will have a constant rated maximum power, so the higher the voltage, the less maximum current will be available. Also note that the average LED current will of course be lower at reduced voltage (around 2.5A per panel at 5V), but will rise quite rapidly as the voltage increases.

The next issue is to do with the display watchdog signals, which are used to inform the QUICC-IDM board that the displays are operating normally. Each watchdog is driven from a monostable on the display panel's transistor card, which is triggered from all the row drive signals. This is optimised for 8V operation, by use of 5.1V zener diode D18 in series with the base of transistor Q32 driving the monostable input. At 5V, the signals will trip out, causing QUICC-IDM to report a fault.

In order to fix this problem, you only need to replace D18 with a 2.7V device, or wire a 2.7V zener in parallel. This is easily achieved due to the number of spare pads in the vicinity of D18, and avoids any damage to the PCB pads due to desoldering. Solder the cathode (banded end) to the JP4 pad nearest D3, and the anode to the third JP5 pad directly opposite. Note that once you have performed this modification, you can still run the display from 8V, but the protection circuit will be much less effective, so this is not recommended.

The other problem with a PC or other computer supply is that it will almost certainly have a minimum load requirement. However, many supplies will not be damaged by low loading, but may go out of tolerance, especially on the auxiliary outputs. Since the auxiliary outputs are not being used, and the main supply voltage is not so critical, this can probably be tolerated. If not, then you will have to make up a load using power resistors, but this is not a desirable solution.

PSU logic control

If your supply does not have any form of control, or its control is not a simple opto input, you will have to use the opto/relay drive circuit on the QUICC-IDM board. For supplies without any control signal, it is best to switch the supply at the mains, using a suitable relay with a snubber network across the contacts. The relay drive could be derived from the 5V or 24V output of the logic supply, or another voltage if this is available. In this case, you should fully construct the QUICC-IDM circuit, and connect up the relay as shown in **figure 3**. Resistors R7 and R8 depend on the voltage being used, the transistor being used, and the relay current, but are typically 3k3 for 12V operation, 6k8 for 24V operation, and 1.5k for 5V operation.

If the PSU has a control signal with a relay input, then you can simply connect the QUICC-IDM circuit to it in the same way as for an external relay. If it has its own driver stage, but this is not opto isolated, then you can simply feed the output of the optoisolator directly to the control signal, as suggested in **figure 4**. In this case, you would omit Q3, D4, R7 and R8 from the QUICC-IDM board. This drive configuration could also be used for other active relay modules that have not got opto-isolated inputs.

Note that many different kinds of opto-isolator can be fitted in place of U4, provided the LED is connected to the correct pins (pins 1, 2 for a 6-pin device, and pins 2, 3 for an 8-pin device). All output pins are brought to PL6 for maximum flexibility. You can use optos with logic or triac outputs, but note that you should avoid feeding voltages of more than about 50V to the board for safety reasons.

Cable assemblies

Having assembled the QUICC board, and chosen suitable PSUs, you are now ready to start assembling an operational system. To do this, you need to construct various cable assemblies that will carry power and data between the various system components. Figure 5 shows a top-level layout diagram of the system, and reference should be made to this when reading the assembly instructions below.

Display Data Cable (multidrop)

This cable consists of a 26-way ribbon cable fitted with four 26-way bump-polarised IDC connectors, and links the three panels to the QUICC-IDM board. A 25-way IDC female D type is fitted to one end (nearest the QUICC-IDM connector), to

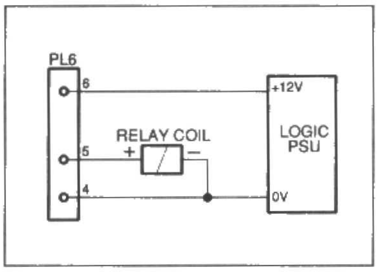


Figure 3: using QUICC-IDM to drive a relay

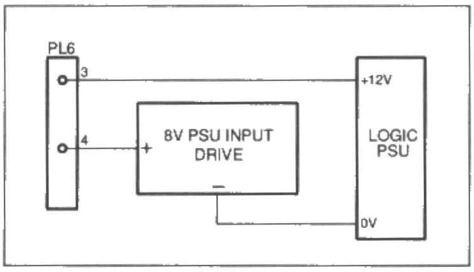


Figure 4: using QUICC-IDM to drive a PSU control signal

allow the data bus to be brought to the outside world. Note that the 26th wire should be cropped just before entering this connector; alternatively you could use 25-way ribbon cable throughout, since the 26th wire is not used.

The parts required are:

4 x 26-way bump-polarised IDC socket (RS 461-219 or Farnell 249-002)
1 x 26-way IDC female D type (RS 470-847 or Farnell 460-205)
1 x 26-way IDC ribbon cable (RS 360-150 or Farnell 297-343)

When constructing this cable, leave about 40cm distance between each of the display panel connectors, and approximately 60cm between the last display panel and the QUICC-IDM board. The remaining length to the D-type should be approximately 30cm. It is a good idea to stand the three panels side by side, and align the connectors before crimping them on. Looking from the front, ensure that the cable starts at the left hand panel, runs to the right hand panel, and from there runs to the QUICC-IDM board.

8V and 24V power cable assembly (3 required)

Each of these cables feeds 8V and 24V into the AMP connector (P8) on the display panel's transistor card. In addition, two spade receptacles provide 0V to connectors P13 and P14 on the CPU card. The suggested pinout of the mating AMP connector is as follows:

1 - 0V wire to spade terminal mating with P13
2 - NC
3 - 0V wire to spade terminal mating with P14
4 - +24V wire to logic PSU
5 - 0V wire to 8V PSU
6 - NC
7 - NC
8 - 0V wire to logic PSU
9 - +8V wire to 8V PSU

Parts required (per display panel):

1 x AMP 9 way socket housing - (RS 848-880 or Farnell 285-195)
1 x socket contact 24-18 AWG - (RS 849-091 or Farnell 285-389 (bag of 100)
1 x socket contact 20-14 AWG - (RS 849-108 or Farnell 285-390 (bag of 100)
2 x standard spade receptacle crimps - (RS 842-270 or Farnell 150-325)

Since up to 5A average current could be flowing through the 8V cables, they should be fairly thick to minimise volt drops. This also applies to the "tails" to the spade terminals, since the ground return current flows through P13 and P14. The 24V supply is very low current, so much thinner cable can be used. Note that the AMP socket contacts should either be crimped (with the correct tool), or soldered. In the latter case, one contact size should suffice for both sizes of cable used.

When the system is assembled in the case, the 8V cables will run to the PSU output on the left (looking from the front of the system), and the 24V cables will run to the logic PSU output on the right. The cable lengths for each panel can be tailored to reflect this, though it's better to make them overlength to be on the safe side. The "tails" to the spade terminals should be approximately 10cm long.

Greenweld have some original cable assemblies available, though the wires are quite short, as they were designed to connect to a bus bar. These assemblies are not advertised, so you will have to ask for them specifically. Last time I visited, they were in a big box near to where the display panels themselves are stored.

5V Display/QUICC-IDM power cable (4 off required)

Each of these cables supplies 5V to a display panel (P16) or QUICC-IDM board (PL3), and uses a standard 3-way Molex housing. The required pinout is:

1 - +5V connection
2 - 0V connection
3 - NC

The cable should be moderately thick, to minimise voltage drops (up to 400mA may flow down each cable). Instructions for constructing such a cable were given in part 1 of this series, to facilitate testing of the QUICC-IDM board. The three remaining cables should be constructed the same way, but the ones to the farthest panels will need to be longer, as they have to run from the display panels to the logic PSU on the left.

PSU Control Cable

This depends on the type of PSU being used, and will either connect to PL2 or PL6 on the QUICC-IDM board. For PL2, pin 1 is the positive connection and pin 2 the negative. For PL6, the connections depend on how the opto drive circuit is being used, and suggested connections are shown in figure 3 and figure 4. Note that PL6 pins 1 and 2 are fed directly to opto-isolator pins, and will only be used under special circumstances.

Configuring the Display Panels

Before a working system can be assembled, the display panels need to be configured correctly. To do this, carefully remove both LED boards from the front of the CPU card, and adjust the links as follows:

All panels:

* JP15 (refresh select) - link the middle pins (3 and 4) only, ensuring others clear.

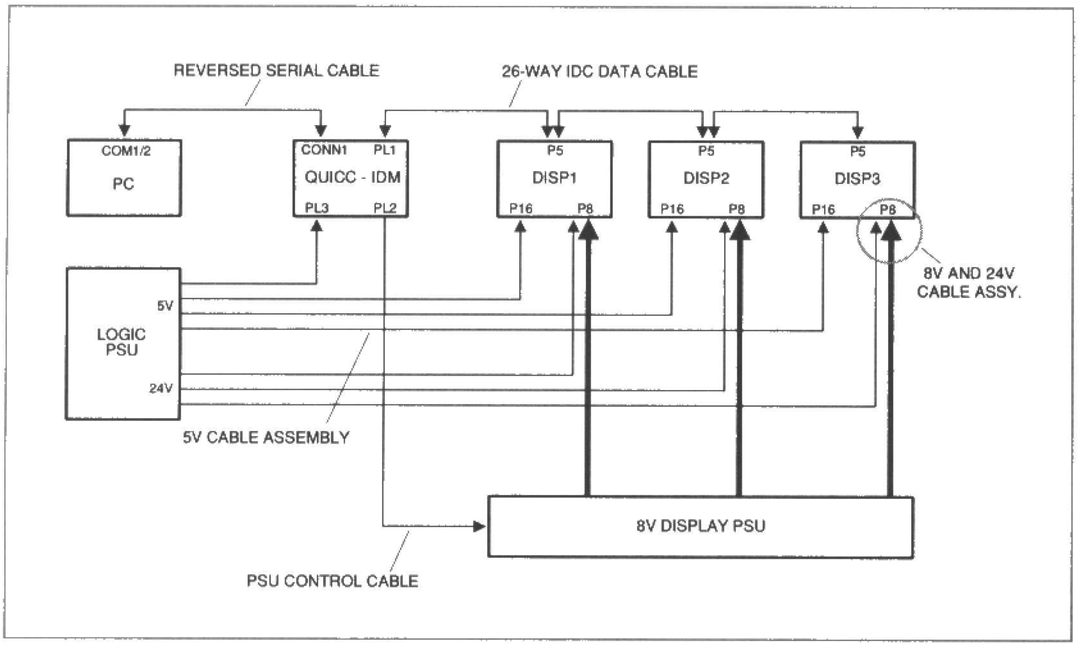


Figure 5: the overall system layout

* JP4 (diagnostics/runtime) - ensure all pins clear (no links).
* JP39 (DMA finish out) - ensure all pins clear (no links).
* P3 (on rear near IDC) - ensure all pins clear (no links).

Panel 1 (left hand side):

* P4 (tile select) - all four links should be made (pins 1, 2 and 3, 4 and 5, 6 and 7, 8)
* JP38 (watchdog out) - link pins 1, 2 and 7, 8 only

Panel 2 (middle position):

* P4 (tile select) - three links between pins 1, 2 and 3, 4 and 5, 6
* JP38 (watchdog out) - link pins 3, 4 and 9, 10 only

Panel 3 (right hand side):

* P4 (tile select) - three links between pins 1, 2 and 3, 4 and 7, 8
* JP38 (watchdog out) - link pins 5, 6 and 11, 12 only

IMPORTANT SAFETY ADVICE

Like all mains powered equipment, this system can be highly dangerous or even fatal if not handled properly. Ensure that all mains connections are sound and well insulated, using adequately rated cable and the correct fusing. Always **turn off all power at the mains before working on the equipment, and beware that power supplies can retain charge for long periods after being switched off.**

The high current display power supply can be particularly hazardous if the output is short circuited, because enough current could flow to cause burns or even set the system on fire. The original 75A PSUs are highly dangerous if mistreated, because an enormous short circuit current could flow, enough to weld metal and cause severe injury. Therefore, you must ensure that all connections are sound and well insulated, and that the protection system offered by QUICC-IDM is not defeated.

System assembly

Having constructed the required cable assemblies, and configured the panels correctly, you are ready to assemble the system (refer to **figure 5** for the layout of the system) . Firstly, wire properly insulated mains leads to the two power supplies, and fit correctly fused plugs. If you are unsure about the condition of the PSUs, then inspect them thoroughly and test them before connecting them to the system. If there are minimum load requirements, use low-voltage light bulbs as loads, and check that the output voltages are within tolerance. The 8V PSU will need the control signal to be activated to bring it on; you can either wait until you are using the QUICC-IDM board, or build your own simple control circuit to test it out.

Next, stand the three panels side by side on a solid surface, and connect all the cable assemblies to them, remembering to connect the earth tags to P13 and P14 on the panels. Run the 8V cables to the left and connect them to the output of the 8V PSU. Run the other cables to the right and connect to the 5V and 24V outputs of the logic PSU. Run the ribbon cable along the back of the system, connecting to all the panels and the QUICC-IDM board. Connect the QUICC-IDM power to the 5V supply, and connect the 8V PSU control signal to the appropriate connector (PL2 or PL6 depending on the PSU). Finally, connect the PC serial cable (described in part 1 last month) to the QUICC-IDM board.

Note that the QUICC-IDM protection circuit should guard against short circuits to the 8V PSU, because it will trip off within 100ms of detecting a voltage drop to the displays. However, with very high current PSUs (such as the original 75A units), a lot of short circuit current could flow before the voltage drops adequately to trip the system. In this case, you may feel safer adding extra output fuses in line with each display panel; these should be rated at approximately 10A, and should be within enclosed in-line fuseholders.

Testing the system

Ensure that the QUICC-IDM standby switch (DIL position 4) is open, all other DIL switches are closed, and apply power to just the logic PSU. Observe that the system attempts to boot but fails, flashing LED1 (Fault) at approximately 1Hz. If this does not occur, and LED3 (Run) remains on, there is a big problem with the display panel wiring, watchdog selects, or the QUICC-IDM board. Turn off the power and check everything thoroughly.

Next open all the watchdog switches (DIL positions 1-3), and press reset. This time the system should remain running. Close switch SW1, and check that it changes to fault reporting mode. Open the switch and repeat the operation for the other two switches in turn. This fully checks out the watchdog signals from the three panels.

Now close all three watchdog switches and apply power to the 8V PSU and check that it does not output any voltage, while QUICC-IDM is still indicating a fault (note that on some supplies, the fan may start running, even when the output is disabled). If it does output a voltage, there is something wrong with the control signal or the PSU itself. Turn off and check the connections carefully. For your own safety, you must ensure the protection system works before proceeding any further.

Now push the reset button, and check that the system starts up and stays running, with all panels displaying a colourful "sign on" message. If it trips off due to a fault, there could be a genuine fault in the system, or the QUICC-IDM PSU override timer is too short. Try lengthening it using the IDMUTIL program with the /p option. If this still doesn't work, check that the PSU starts outputting a voltage before it shuts down, and if this is the case, suspect a display panel fault. Run the QDSL program with a test script (see below), and when it reports a failure, check which panel(s) it reported as causing the fault. Depower the system and check the watchdog link settings on the affected panel(s).

Once you have got this far, you can now start using QDSL to check that the PC can drive the displays. Run it with the TEST.DSL script file, and check that a display appears on all three panels, correctly identifying them as panels 1, 2 and 3 from left to right. Also check that the two "flash" messages are correctly toggling in antiphase on all the panels (if not then check the PL8 links, or the DTR signal from the PC). If you don't get anything, then there could be a fault in the serial cable to the PC, or the DTE/DCE links on PL7. If only some panels are updating, then there could be a fault in the ribbon cable to the affected panels.

Close the standby switch (DIL position 4) or short pins 1 and 2 of PL4 if this is not connected. Check that the system shuts down approximately 42 seconds after you stop the PC software, and that it starts up smoothly when QDSL is restarted. Also check that QDSL displays all three panels as being fitted, and then turn off the 8V supply while it is running; shortly after this, QDSL should exit, and display a message indicating all panels as showing the fault, both currently and when the system tripped. If it does not do this, there could be a problem with the DSR line to the PC, either in the serial cable or the PL7 links.

As long as the system is working smoothly, you could open each watchdog switch in turn, and check that with the 8V PSU off, QDSL reports the corresponding panel as not being present, and not reporting the fault. If you want to simulate panel faults, you could disconnect the AMP connector from P8 on the rear of one panel, apply 8V and start the system; QDSL should then display a message indicating all panels currently showing a fault, but only the affected panel as showing the fault when the system tripped.

If you've got to this point, then you have a fully working system. Next month I will describe how to construct a suitable enclosure and build the system into it. In the meantime, have a look at the text files that accompany the software and have a go at writing your own scripts.

ModsMods

We have some small errors reported from Part 1 last month. Most important, in Figure 1, page 42, the QUICC-10M circuit diagram, resistor R18 (330R)should be shown on the line between pin 2 of PL10 (bottom centre) and LED4. The Reset switch SW2 (botton left hand corner) should go to ground between the switch and PL4 pin 2. These are shown correctly on the overlay in figure 2. In figure 2, page 44, Pin 1 of connectors PL2, PL3 and J1-4 should be marked on the left hand end in each case. In the case of J104, pin 1 goes to the anodes of the LEDs connected. Also in figure 2, the annotations intended for PL4 have migrated in order but in error to the adjacent IC4. The caption says IDM instead of 10M (and has sprouted a clone under the photo of the display on page 41) but is otherwise correct.

Hardware

As described last month, **the Display Panels** can be purchased from myself or Greenweld Electronics as surplus items (**Greenweld Electronic Components, 27E Park Road, Southampton, SO15 3UQ. Tel 01703 236363 Fax 01703 236307**), and currently cost £15 each inclusive. Some units suffered minor damage while being removed from the original system, so it is a good idea to request panels in good condition. I have also found manufacturing faults in a few of them, including unsoldered joints, an eprom leg bent under the device, and a reversed polarity reset capacitor that was causing the panel to shut down intermittently. Inspect each panel carefully for this type of fault before using it in this system.

The double-sided **Controller PCB** currently costs £40: the price includes the pre-programmed PIC (not copy protected), and a disk containing all the PC software, documentation, and the PIC hex files. The PIC source code is not included, though you can buy it directly from myself - please enquire. If you intend to make your own board, I can supply the PIC and software for £20. If you wish to obtain display panels and/or QUICC-IDM controller PCBs from myself, please write to: **R. A. Coward, 22 Alexandra Park, Queen Alexandra Road, High Wycombe, Bucks HP11 2HJ or email enquiries to rcoward@dev.madge.com.** Service by mail order only; please do not telephone or call. Please make cheques payable to R A. Coward and add £9 postage and packaging to any order that includes, or £5 if you are only buying boards and software. Display panels have not been inspected or tested. While I would attempt to ship the order as quickly as possible once payment has been received, please allow up to 28 days for delivery. Other details are given in the Parts List in last month's issue.

Farnell Electronic Components: Canal Road, Leeds LS12 2TU Tel 0113 2636311. Tel 0113 279 0101.

TELL THEM YOU SAW IT HERE...

Readers: Please mention ETI when replying to advertisements

To advertise in ETI, call Mark Colyer on 01322 660070

Getting MORE out of PICs

Part 6

Robin Abbott

The sixth and last part: Arithmetic Routines

In this month's article I shall take a look at a number of routines which may be used for arithmetic on 32 bit numbers. There are relatively few applications for micro controllers which require a wide range of arithmetic routines, however typical applications include processing of real world input information, calibration, and simple signal processing. The routines are intended to be as simple to use as possible. For example the code to evaluate the expression y/100000+x*45 where x and y are 32 bit variables in memory is accomplished in just 16 words of program memory as follows:

```
movlw k100           ; Constant 100000
call Load32          ; Load into accumulator
call CopyAccAcc2     ; Copy to 2nd accumulator
movlw y
call LoadAccMem      ; Load y into accumulator
call Divide          ; divide y by 100000
PushAcc              ; Save y/100
movlw x
call LoadAccMem      ; Load x into accumulator
call CopyAccAcc2     ; Copy into 2nd accumulator
movlw .45
call Load8           ; Load 45 into accumulator
call Multiply        ; Accumulator holds 45*x
call PopAcc2         ; Accumulator 2 holds y/100000
call Add             ; Accumulator holds 45*x+y/100000
```

The arithmetic routines that I shall present operate using a stack, a main accumulator, and a secondary accumulator. As 4 byte variables are used there is quite a high impact on RAM usage, for this reason the routines have all been tested on a 16C74.

To assist in understanding the documentation of the program, all call labels are shown in bold, and program variables are shown in italics.

Although all of the routines shown operates with 32 bits accuracy, in practice it is straightforward to operate at 16 bit or 8 bit resolution. Please note that 32 bit operation is necessary when performing calculations which produce an intermediate results which overflows with 16 bit precision. For example in signed arithmetic the equation y=3x/2 requires 32 bit precision for all values of x greater than 10922 even if the result fits into 16 bits. It is also possible with 32 bit operation to emulate floating point routines, for example multiplying by a 0.0062 is equivalent to multiplying by 62 and dividing by 10000, and with 32 bits this calculation can be reliably performed for all 16 bit numbers.

As is usual in Intel and Zilog processors, data is represented in the memory with the lowest significant byte at the lowest address in the memory. The most significant bit of the integer is used to indicate a negative value. It is possible to achieve greater precision with unsigned values by changing the routines so that the top bit is the most significant bit of the unsigned integer.

The stack

It is possible to undertake arithmetic on a micro controller using a number of utility functions, and to move data around memory between variables and accumulator as required. However, complex arithmetic routines normally require intermediate results to be held, which results in having to store values in a number of temporary registers. It is much more straightforward to operate using a stack, where intermediate results may be stored and recalled as required. Unfortunately the PIC series of micro controllers have (at least the 16Cxxseries) no software accessible stack. This implies that the user must set up such a stack using software routines. This slows the operation of the program, but is essential to implement a stack. Stack manipulation routines are quite simple to write, and once written may be included in any programs, and find use in normal PIC applications whether they use arithmetic routines or not.

Listing 1 shows the stack manipulation routines. There is a single variable called sp which acts as the stack pointer, it should be initialised to a value at the top of RAM. sp always points to the first unused byte on the stack, a byte is written to its value and then it is decremented when pushing information and vice versa to pop information. PushAcc and PopAcc push and pop the accumulator. PushW and PopW operate on the W register and are useable by any routine. Note that if PushW and PopW are to be used in interrupt routines then interrupts should be disabled at the entry and exit points of the routines.

Listing 1

```
; Maths routines
;
; Defines
;
WordSize      equ 4                    ; Size of integer in bytes
;
; Macros to increment and decrement memory pointers past
  configuration memory
; implemented as macros for speed
; These routines must be modified to suit the processor in use
;

labcnt=0                               ; Label counters for macro
labcnta=0
INCMEM        MACRO freg               ; Increment register
pointing at memory
              btfsc freg,7             ; No effect if bit 7 set
              goto uppr#v(labcnt)
              incf freg                ; Hop from 7F to A0 on
                                       incrementing
              btfsc freg,7
              bsf freg,5
              goto endi#v(labcnta)
uppr#v(labcnt)  incf freg
              labcnt=labcnt+1
endi#v(labcnta)
              labcnta=labcnta+1
              ENDM

DECMEM  MACRO freg                     ; Macro to decrement reg.
                                       pointing at memory
LOCAL         endec
              decf freg
              btfss freg,7             ; If bit 7 set and ...
              goto endec
              btfsc freg,6
goto endec
              btfsc freg,5             ; bit 5 reset then hop
                                       down to 7f
              goto endec
              incf freg
              bcf freg,5
              decf freg
endec
              ENDM
;
; Variables
;
    Acc     equ     0x20               ; Start of memory area
                                       for '74
    Acc2    equ     Acc+WordSize       ; Secondary
                                       Accumulator
```

```
    sp      equ     Acc2+WordSize  ; Stack pointer
    x       equ     sp+WordSize    ; 32 bit variables
    y       equ     x+WordSize

    cblock y+WordSize+1
    spTemp
    Temp    ; Temporary registers
    Temp1
    Temp2
    Temp3
    Temp4
    Temp5
    Temp6
    Temp7
    Temp8
    Temp9
    Temp10
    Temp11
    Temp12
    DivIndex
    endc
;
; Routines for the stack
;
; Push and pop the W register to the stack

PushW       movwf spTemp
    movfw sp
    movwf FSR          ; Indirect access
    movfw spTemp
    movwf 0            ; Write Value
    DECMEM sp
    return

; Pop W

PopW        INCMEM sp                  ; Next value
    movfw sp
    movwf FSR
    movfw 0
    return

; Push Accumulator

PushAcc     movfw Acc+3                ; Simply push 4 bytes
                                       from accumulator
                                       address
    call PushW
    movfw Acc+2
    call PushW
    movfw Acc+1
    call PushW
    movfw Acc
    goto PushW

; Push Accumulator 2

PushAcc2    movfw Acc2+3               ; Simply push 4 bytes
                                       from accumulator
                                       address
    call PushW
    movfw Acc2+2
    call PushW
    movfw Acc2+1
```

```
          call PushW
          movfw Acc2
          goto PushW

; Pop Accumulator

PopAcc    call PopW          ; Pop 4 bytes from stack.
          movwf Acc
          call PopW
          movwf Acc+1
          call PopW
          movwf Acc+2
          call PopW
          movwf Acc+3
          return

; Pop Accumulator 2

PopAcc2   call PopW          ; Pop 4 bytes from stack.
          movwf Acc2
          call PopW
          movwf Acc2+1
          call PopW
          movwf Acc2+2
          call PopW
          movwf Acc2+3
          return
```

Listing 1 includes the header information to define variables and registers in RAM, note that a large number of temporary registers are defined for use in the later routines - division in particular requires large temporary store. The macros INCMEM and DECMEM are shown for the 16C74, they should be written so that unusable areas of RAM may be skipped, for example in the 16C74 then memory from 80H to 9FH is configuration variables and therefore if sp is at address A0H then when DECMEM is called it will set sp to 7FH skipping the configuration area. This is illustrated in **figure 1**.

Arithmetic accumulators

The main accumulator is called Acc, and the secondary accumulator is called Acc2. All binary arithmetic operations apply to both accumulators and leave the result in Acc, unary operations simply apply to Acc.

To manipulate the data, We shall write a number of simple routines to move data between the memory and the accumulators, and between the accumulators and the stack. **Listing 2** shows these routines. At the heart of these routines is a general purpose module which copies 4 bytes of data (which is an arithmetic word) from the address held in FSR to the address held in the W register. This is called CopyData.

The routine called SwapAcc swaps the two accumulators by making use of the stack. The two other routines copy one accumulator to the other, CopyAccAcc2 moves Acc to Acc2, and CopyAcc2Acc moves data from Acc2 to Acc.

Listing 2

```
;
; Routines to move data around
;
; Swap accumulators

SwapAcc      call PushAcc
             call CopyAcc2Acc
             goto PopAcc2

; Copy accumulator to memory address

LoadMemAcc       movwf Temp
                 movlw Acc
                 movwf FSR
                 movfw Temp
                 goto CopyData

; Load Accumulator from memory address in W

LoadAccMem       movwf FSR
                 movlw Acc
                 goto CopyData

; Copy accumulators

CopyAccAcc2      movlw Acc       ; Copy accumulator to Acc2
                 movwf FSR
                 movlw Acc2
                 goto CopyData

CopyAcc2Acc      movlw Acc2      ; Copy Acc2 to Accumulator
                 movwf FSR
                 movlw Acc
                 goto CopyData

; Copy data from address in FSR to address in W

CopyData         movwf Temp
                 movlw WordSize
                 movwf Temp1     ; byte counter
CDLoop           movfw 0
                 movwf Temp2     ; Data byte to copy
                 movfw FSR
                 movwf Temp3     ; Save Destination address
                 movfw Temp
                 movwf FSR
                 movfw Temp2
                 movwf 0
                 incf Temp
                 incf Temp3
                 movfw Temp3
                 movwf FSR
                 decfsz Temp1
                 goto CDLoop
                 return
;
; Other useful routines
;
; Clear Accumulator

ClrAcc       clrf Acc
Clr3         clrf Acc+1
Clr2         clrf Acc+2
             clrf Acc+3
             return
```

```
; Clear Accumulator2

ClrAcc2  clrf Acc2
                    clrf Acc2+1
                    clrf Acc2+2
                    clrf Acc2+3
                    return
```

There are two routines to copy data between RAM variables and the main accumulator Acc. LoadAccMem and LoadMemAcc are called with a label address in W, and they then move values to the main accumulator from a memory address, or back in the other direction.

Loading constants

The constant functions will place a constant value into the main accumulator. A simple eight bit value may be loaded into W and sign extended into the main accumulator using routine Load8. Sex8 sign extends from Acc into the higher order registers.

In other processors it is possible to include a data byte in program memory following a call instruction, and this may be used to include data in the program area. However in the PIC it is not possible to do this (again due to stack limitations). For this reason our other two routines to load 16 and 32 bit values into the accumulator rely on a data table being set up which contains the 16 and 32 bits of values which are accessed as required. **Listing 3** shows the routines which load constant values, and also an example of a data table.

Listing 3 - loading constant values

```
;
; Load an 8 bit value in W into the main accumulator
;

Load8          movwf Acc
;
; Call here to sign extend an 8 bit value across Acc
;
SexAcc         call Clr3
               btfss Acc,7
               return
               decf Acc+1
               decf Acc+2
               decf Acc+3
               return
;
; Load a 16 or 32 bit value from data address in W to
Accumulator
;
Load32         movwf Temp
               movlw Acc
               movwf FSR
               movfw Temp
               goto Load32W

Load16         call Clr2
               movwf Temp
               movlw Acc
               movwf FSR
               movfw Temp
               goto Load16W
;
; Load 32 or 16 bit value from program memory in W to RAM
address in FSR
;

Load32W        movwf Temp
               movlw 4
               movwf Temp1          ; Byte counter
               goto LoadLoop
Load16W        movwf Temp
               movlw 2
               movwf Temp1          ; Byte counter
LoadLoop       movlw ConsTab>>8     ; Upper address of
constant table
               movwf PCLATH
LL1            movfw Temp
               call GetDataVal      ; Get value from program
memory
               movwf 0
               incf Temp            ; Next address
               incf FSR
               decfsz Temp1
               goto LL1
               return
;
; This is the constant table placed at a high memory address
to avoid ; problems with crossing page boundaries
;
               org 0x700

GetDataVal     movwf PCL            ; Indirect call

ConsTab
TestValue      retlw 0x78           ; Test value 0x12345678
               retlw 0x56
               retlw 0x34
               retlw 0x12

TestValue2     retlw 0xff           ; Test value 0x12345678
               retlw 0xff
               retlw 0xff
               retlw 0xff

k100           retlw .100000        ; This is the value 100000
                                    decimal
               retlw .100000>>8
               retlw .100000>>.16
               retlw .100000>>.24
```

Arithmetic operations -,+,*,/

Listing 4 shows the addition and subtraction routines. The first routine negates either the main accumulator, or the secondary accumulator. As we shall see, this routine allows us to undertake subtraction, multiplication, and division more straightforwardly than if we had to undertake these operations on signed values. Addition is straightforward and is shown in Add. Subtraction (Subtract) is achieved by negating the value in the secondary accumulator, and then flowing down into the addition routine.

Listing 4 - Addition and subtraction

```
;
; Routine to negate Acc
;
```

```
NegAcc      comf Acc           ; Negate by Complement
                               & Increment
            comf Acc+1
            comf Acc+2
            comf Acc+3
            goto IncAcc

NegAcc2     call SwapAcc       ; Negate Acc2 and
            call NegAcc
            goto SwapAcc

; Routine to increment Acc

IncAcc      incfsz Acc
            return
            incfsz Acc+2
            return
            incf Acc+3
            return
            incf Acc+4
            return

Subtract    call NegAcc2       ; Acc=Acc+(-Acc2)
Add         movfw Acc2
            addwf Acc
            skpnc
            call CAH
            movfw Acc2+1
            addwf Acc+1
            skpnc
            call CA32
na32        movfw Acc2+2
            addwf Acc+2
            skpnc
            incf Acc+3
            movfw Acc2+3
            addwf Acc+3
            return

; Ripple carry add on Accumulator

CAH         incfsz Acc+1
            return
CA32        incfsz Acc+2
            return
CA32H       incf Acc+3
            return
```

Listing 5 shows the multiplication routine Multiply. This routine first checks to see if either the values have the same sign, if they do then they are both converted to a positive integers, and then multiplied. If either value is negative, whilst the other is positive, then the negative value is converted to a positive value, both values are multiplied, and finally the result is converted back to a negative integer. The multiplication routine operates by undertaking a continued shift and conditional add sequence, the binary equivalent of long multiplication as readers may recall from their early school days!

The division routine - Divide - operates in exactly the same way as the multiplication routine to convert values to positive integers for the division, correcting the sign after the operation. Note that the division routine contains both the integer result of the division, and the modulus of the result which is stored in Temp7 to Temp10, this value may be moved back to memory or an accumulator using CopyData if a modulus routine is required.

Listing 5 - Multiplication and Division

```
;
; Multiply and divide routines
;
; Signed Divide :  Acc/Acc2 result in Acc, remainder in Temp7-
Temp10

Divide      call prepmd        ; Prepare for Mul/Div
Divi1       clrf Temp7
            clrf Temp8
            clrf Temp9
            clrf Temp10
dloop       clrc
            rlf Temp3
            rlf Temp4
            rlf Temp5
            rlf Temp6
            rlf Temp7
            rlf Temp8
            rlf Temp9
            rlf Temp10
            movfw Acc2+3
            subwf Temp10,w
            skpz
            goto nochk
            movfw Acc2+2
            subwf Temp9,w
            skpz
            goto nochk
            movfw Acc2+1
            subwf Temp8,w
            skpz
            goto nochk
            movfw Acc2
            subwf Temp7,w
nochk       skpc
            goto nogo
            movf Acc2,w
            subwf Temp7
            btfss STATUS,C
            call CA8           ; Carry over to Temp8
            movf Acc2+1,w
            subwf Temp8
            btfss STATUS,C
            call CA9
            movf Acc2+2,w
            subwf Temp9
            btfss STATUS,C
            decf Temp10
            movf Acc2+3,w
            subwf Temp10
            bsf STATUS,C
nogo        rlf Acc
            rlf Acc+1
            rlf Acc+2
            rlf Acc+3
            decfsz DivIndex
            goto dloop
```

```
                goto postmd
;
; Handle rippling carry for subtraction
;
CA8             movlw 0xff
                addwf Temp8
                skpnc
                return
CA9             movlw 0xff
                addwf Temp9
                skpnc
                return
CA10            decf Temp10
                return

; multiply AritAcc*Temp

Multiply        call prepmd
mulloop         btfss Acc2,0
                goto noadd
                movfw Temp3
                addwf Acc
                skpnc
                call CAH
nm1             movfw Temp4
                addwf Acc+1
                skpnc
                call CA32
nm2             movfw Temp5
                addwf Acc+2
                skpnc
                incf Acc+3
```

```
                movfw Temp6
                addwf Acc+3
noadd           rlf Temp3               ; Temp 3/4 *= 2
                rlf Temp4
                rlf Temp5
                rlf Temp6
                bcf Temp3,0
                rrf Acc2+3
                rrf Acc2+2
                rrf Acc2+1
                rrf Acc2
                decfsz DivIndex
                goto mulloop
                goto postmd

;
; Routine to negate arguments for multiplication or division
;
prepmd          movfw Acc+3             ; check if signs are
                                        different
                xorwf Acc2+3,w
                movwf Temp12            ; Temp12 holds the sign
                btfsc Acc+3,7
                call NegAcc
                btfsc Acc2+3,7
                call NegAcc2
EndPre          movlw WordSize*8        ; Number of bits
                movwf DivIndex
                movfw Acc
                movwf Temp3
                movfw Acc+1
                movwf Temp4
```

Table 1 - Complete list of arithmetic routines

Routine	Call Parameters	Notes
Add	-	Accumulator=Accumulator+Accumulator2
ClrAcc	-	Clear Accumulator
ClrAcc2	-	Clear Accumulator 2
CopyAcc2Acc	-	Copy Accumulator2 to Accumulator
CopyAccAcc2	-	Copy Accumulator to Accumulator2
CopyData	FSR holds source address W holds destination Address	Copy 4 bytes from FSR to W
Divide	-	ccumulator=Accumulator/Accumulator2 Temp7-Temp10= Accumulator%Accumulator2
IncAcc	-	Increment the accumulator
Load16	W holds address of constant data in program memory	Load a 16 bit value from program memory into the accumulator
Load32	W holds address of constant data in program memory	Load a 32 bit value from program memory into the accumulator
Load8	W holds constant value	Load an 8 bit value and sign extend into the accumulator
LoadAccMem	W holds memory address	Load Accumulator from memory location
LoadMemAcc	W holds memory address	Save Accumulator to memory location
Multiply	-	Accumulator=Accumulator*Accumulator2
NegAcc	-	Negate the accumulator
NegAcc2	-	Negate accumulator 2
Subtract	-	Accumulator=Accumulator-Accumulator2
SwapAcc	-	Swap Acc and Acc2

```
          movfw Acc+2
          movwf Temp5
          movfw Acc+3
          movwf Temp6
          goto ClrAcc
postmd    btfss Temp12,7        ; check sign bit
          return
          goto NegAcc
```

We now have the basis of a useful arithmetic module. **Table 1** shows all the routines and their calling methods within the arithmetic routines.

Enhancing the routines

The routines shown form the basis of an arithmetic package which may be of use for a wide number of applications. It would be preferable to enhance the 8 and 16 bit load and save capabilities to enable variables to be stored in less bytes in memory but still use the full 32 bit precision shown, and further routines to allow data to be moved between Acc2 and memory would make manipulation of data and equations more straightforward.

Obtaining code

At the end of this series a disk with all the examples shown in the series will be available, the programs may also be downloaded from the web at www.aaelectron.co.uk/eti

The author is a happy to answer questions on the series by email. Write to him at robin.abbott@dial.pipex.com.

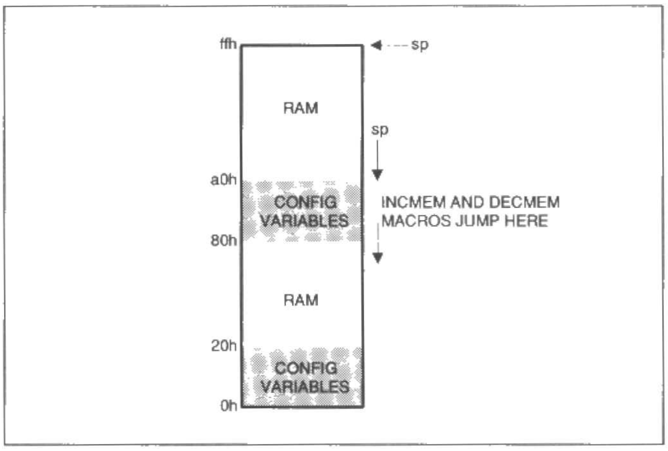


Figure 1: 16C74 memory map and operation of stack pointer (sp)

TELL THEM YOU SAW IT HERE...
Readers: Please mention ETI when replying to advertisements
To advertise in ETI, call Mark Colyer on 01322 660070

HOW DOES YOUR EQUIPMENT MEASURE UP? AT STEWART OF READING THERE'S ALWAYS 'SCOPE' FOR IMPROVEMENT!

AUTUMN SALE
PHILIPS PM3217
Dual Trace 50MHZ Delay
This really is a very good oscilloscope Including 2 Probes, Pouch & Front Cover
Only £300

THIS IS THE BEST CHEAP SCOPE YOU WILL EVER BUY!!!
£200
Gould OS1100 Dual Trace 30MHz Delay. Very Bright. Supped with manual & 2 probes.

TEKTRONIX 2215 - Dual Trace 60MHZ
Sweep Delay, includes 2 probes
Only £350

TEKTRONIX 400 SERIES

468 Digital Storage Dual Trace 100MHZ Delay	£550
466 Analogue Storage Dual Trace 100MHZ Delay	£250
485 Dual Trace 350MHZ Delay Sweep	£750
475 Dual Trace 200MHZ Delay Sweep	£450
465 Dual Trace 100MHZ Delay Sweep	£350

HC 3502
Dual Trace 20MHZ
5mV-20V/Div; 0.2u secs-0.5 Sec/Div; X-Y; X5 Magnifier; TVSync etc.
Un Used £180

PHILIPS PM3296A Dual Trace 400MHZ Dual TB Delay Cursors IEEE	£2250
FLUKE PM3082 2+2Ch 100MHZ Delay TB Cursors	£950
TEKTRONIX 2465 4 Ch 300MHZ Delay Sweep Cursors etc	£2000
TEKTRONIX 2445/2445A 4 Ch 150MHZ Delay Sweep from Cursors etc	£1000
TEKTRONIX TAS465 Dual Trace 100MHZ Delay Cursors	£900
TEKTRONIX 2235 Dual Trace 100MHZ Delay Sweep	£700
IWATSU SS5711 4 Ch 100MHZ Delay Sweep	£550
PHILIPS 3055 2+1 Ch 50MHZ Delay DualTB	£475
GOULD OS300 Dual Trace 20MHZ	£160

MARCONI 2019 Syn AM/FM Signal Gen 80KHZ–1040MHZ	£1200
MARCONI 2017 Phased Lock AM/FM Signal Gen 10KHZ–1024MHZ	£1500

Can You Believe It - A 1GHz Generator for only £450
H.P. 8640A AM/FM Signal Gen
500KHZ–1024MHZ – Audio Option

H.P. 8640A AM/FM Signal Gen 500KHZ-512MHZ	£250
FARNELL PSG520 Syn AM/FM Sig Gen 10–520MHZ Portable	£450
MARCONI 6311 Programmable Sweep Gen 10MHZ–20GHZ	£4500
PHILIPS PM5193 Programmable Syn Func Gen 0.1MHZ–50MHZ	£1500
PHILIPS PM5192 Programmable Syn Func Gen 0.1MHZ–20MHZ	£1000
H.P. 3325A Syn Function Gen 21MHZ	£950
PHILIPS PM5134 Sweep Func Gen 0.001HZ–20MHZ	£300
PHILIPS PM5132 Sweep Func Gen 0.1HZ–2MHZ	£200

CLASSIC AVO METER
A Digital AVO DA116 31/2 digit
Complete with Batteries and Leads
Only £30

METROHM - 9A - 500V Battery Meggar (a useful back-up for fault finding) Complete with Batteries & Leads Only £35

SOLARTRON 7045 - 4.5 Dig. Bench Multimeter with leads £45

SOLARTRON 7151 DMM 61/2digit IEEE	£450
SOLARTRON 7150 DMM 61/2digit IEEE	£300

True RMS

LOOK
BRAND NEW OSCILLOSCOPES – NEVER USED LIMITED STOCK

DMS 3850A DIGITAL STORAGE/DMM
Handheld LCD Display 2 Channel 50MS/S. Auto range. 4 digit DMM/Capacitance/Frequency Counter Battery Operation or external 7.5-9VDC ie. AC Adaptor (Not supplied). RS232 Comes in Black Carrying Pouch complete with 2 scope probes; DMM leads; Manual
FOR ONLY £400

DTS 40 DIGITAL STORAGE
Dual Trace 40MHZ 20MS/S Storage. Cursors + On Screen Readout. Sweep Delay; Interface etc. etc. Supplied Unused in original box complete with 2 Probes & Manual
AMAZING VALUE AT £400

DTA 20
Dual Trace
20MHz
Alt Mag, TV Trig etc. Unused & boxed supplied with 2 probes & Manual £225

FARNELL PSG1000
10KHZ - 1GHZ
Am/Fm Synthesised Signal Generator
Portable - Un-Used £1500 Used £995

FARNELL AMM2000
Sophisticated Automatic Modulation Meter 10HZ - 2.4GHZ (Looks similar to above PSG1000)
Un-Used £1250

WAYNE KERR AMM255
Automatic Modulation Meter
AM/FM 1.5MHZ - 2GHZ 31/2 Digit
Un-Used £500

DUMMY LOAD 'N' Type 50ohm 75 Watts
Un-Used £30

NEW & HARDLY USED

PANASONIC VP8177A FM/AM SIGNAL GENERATOR
100KHZ–100MHZ; FM 0 –100KHZ; Output –10dB–99dB AM 0-60%; 32 Preset Memory; Digital Display Frequency & Output.
Used £450 Un-Used £750

KENWOOD FL180A WOW/FLUTTER METER
0.003%–10%. Freq 3KHZ/3.15KHZ
RMS/AVERAGE/PEAK: Weighted Filters; Digital Display or rpm; 4 digit Freq Counter (0.01KHZ–9.999KHZ/0/01KHZ–55KHZ)
Used £400 Un-Used £500

POWER SUPPLY MODEL HSP3010
0-30 Volts; 0-10 Amps
Current Limiting. 2 Meters
Used £160 Un-Used £200

GOODWILL
GVT427 DUAL CHANNEL AC MILLIVOLTMETER
10µV 300V in 12 Ranges
Frequency 10HZ – 1MHZ
Used £100 Un-Used £125

GOODWILL GFC 8010G
FREQUENCY COUNTER Range
1HZ – 120MHZ 8 Digit Display 15mV
RMS Sensitivity Un-Used £75

ANALOGUE MULTIMETER Model HC260TR AC/DC Volts; DC Current 10Amps; 17 Ranges; Continuity Buzzer; Transistor Tester Un-Used £15

STEREO AUDIO BALANCE to UNBALANCED CONVERTOR ie For Car Radio Servicing Un-Used £10

FARMELL LFI Sine / Sq Oscilla
10HZ - 1MHZ £75

POWER SUPPLIES

FARNELL AP100/30 0-100Volts, 0-30Amps Auto Ranging	£1000
FARNELL H60/25 0-60Volts, 0-25Amps	£400
FARNELL TSV70Mk2 70Volts, 5Amps/35Volts 10Amps	£200
FARNELL L12-10C 0-12Volts, 0-10Amps	£175
FARNELL LT30-2 0-30Volts, 0-2Amps Twice	£160
FARNELL LT30-1 0-30Volts, 0-4Amps Twice	£130
THURLBY-THANDAR TSX1820 Precision PSU 18Volts, 20Amps	£275
THURLBY PL320 0-30Volts, 0-2Amps GPIB Digital	£150
THURLBY PL310 0-30Volts, 0-1Amps Digital	£110

MANY MORE POWER SUPPLIES AVAILABLE
Mains Isolating Transformer 3KVA. Cased 13 Amp Plug & Socket. As New £100

Access
STEWART of READING
110 WYKEHAM ROAD, READING, BERKS. RG6 1PL
Telephone: (0118) 9268041. Fax: (0118) 9351696
Callers Welcome 9 am - 5.30 pm Monday to Friday (other times by arrangement)
VISA

Used Equipment – GUARANTEED. Manuals supplied
This is a VERY SMALL SAMPLE OF STOCK. SAE or Telephone for lists. Please check availability before ordering. CARRIAGE all units £16. VAT to be added to Total of Goods and Carriage.

The Versatile Diode

Diodes do other things besides rectifying. Keith Garwell sketches applications for temperature reading, current sensing and mains switching

Diodes invariably end up as rectifiers, whether it be for the mains in power supplies or at higher frequencies for AM detection and suchlike. However they do have characteristics which make them very useful for other tasks.

I am going to look at these diode characteristics, in particular characteristics of silicon diodes. There can be simplified as in **Figure 1**, which shows an equivalent circuit to a diode as being a resistor in series with a rectifier in series with a voltage source while in parallel with a capacitor. (They used to be called condensers in my day!) This is an approximation: the actual characteristic of a diode is exponential, so that even if the resistance were zero, the current would not be 0 below 0.6V and unlimited above 0.6V. However, this simplification is sufficient for the present purpose.

In the equivalent circuit the rectifier is perfect, that is, with a potential applied in one direction it conducts electricity with no losses, and with a potential applied in the other direction it is a perfect insulator.

The voltage source Vs for a silicon diode is around 0.6V at room temperature, but varies inversely at a rate close to 2mV per degree C. As the temperature rises so the voltage will fall. The resistance R is dependent upon the physical dimensions of the diode. It is considerably less than 1 ohm for diodes in power supplies and around 200 ohms for small signal diodes. The capacitance also is dependent upon the physical dimensions, and has the effect of apparently slowing down the turn-off/turn-on time of the rectifier. This will not affect the applications which follow.

These circuits are applications rather than projects, with the mains applications for more experienced constructors looking for handy ideas. The thermometer however can be built by anyone

Application 1

One of the simplest applications of the silicon diode is as a thermometer. The voltage across it is dependent upon temperature, and small diodes like the 1N4148 size make very useful temperature probes. For the very best accuracy, a constant current source must be used to eliminate the effect of series resistance which, with a variable current, would alter the change in voltage with change in temperature.

If you have a DVM with a diode test facility which gives the voltage across the diode, all it needs is calibration which we will consider shortly.

Failing the availability of a ready-made diode test, the circuit in **figure 2** can be pressed into use with a DVM. R1 is not critical, but if it is too low the current through the diode will be sufficient to heat it, and if it is too high the input resistance of the DVM will be a consideration. A value of 47k works well with a 5V supply. The 5 volts must be regulated, or any change in the current through the diode will cause a change in voltage due to its internal resistance (R in figure 1). The simplest answer is a 5-volt regulator and a 9-volt battery.

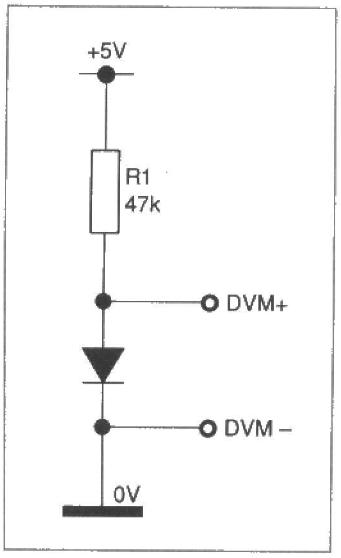


Figure 2: a circuit which can be used with a DVM to employ a small-package diode as a temperature probe

If you have not got a DVM you can use, then you can use the circuit in **figure 3**, as this will supply sufficient output current to drive a moving coil meter. It is a fairly simple DC amplifier with a means of setting two temperatures, for example 0 degrees C and 100 degrees C. As I do not know what moving coil meter you have, I can only suggest example values for R5 and R6. Suppose it has a 1-volt range and you wish to make this cover 0 to 100 degrees C. The variation in diode voltage will be about 200 millivolts and this must be amplified to 1 volt, that is by five. At the same time it must be possible to set the output voltage to zero at 0 degrees C.

As an example, let's take R5 as 100k. R6 must then be 500k to give the required gain, so a 1M pot or preset will do for the first trial calibration.

For the circuit in **figure 3** the 5 volts can be obtained via a 9V battery and a 5V regulator as mentioned before. The IC (pin 7) should be supplied with 9V from the battery. This will allow the ouput to be driven up to 5 volts. The point here is that the ic used here is a CA3140. This ic will operate down to a 0V output. The highest output voltage obtainable from the ic is about 2.25 less than the voltage at pin 7. To allow the battery voltage to fall by, say, 1.5 volts during its life, a maximum output of 5V is a reasonable expectation. To achieve more than 5V the supply voltage must be increased by the required amount. Both the ic and the regulator will tolerate up to 30V.

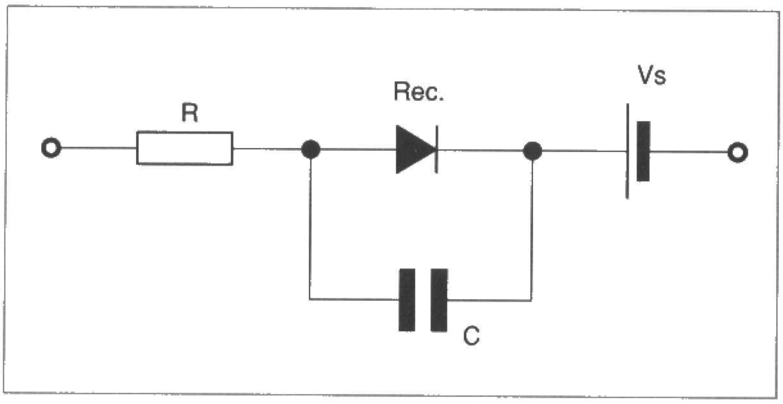


Figure 1: a diode is roughly equivalent to a resistor in series with a rectifier in series with a voltage source and in parallel with a capacitor

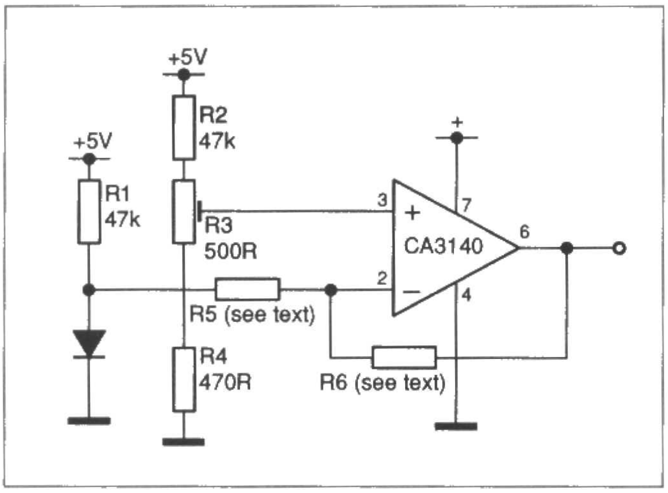


Figure 3: a DC amplifier circuit giving sufficient output current to drive a moving coil meter

Construction

There are no special requirements for application 1. The circuit in figure 2 can be built into a small plastic box large enough to accommodate R1, the regulator, battery, an on/off switch, and two pairs of sockets: one for the DVM and one to connect the diode probe. It's a good idea to make them coloured sockets for easy identification. It hardly needs saying that correct polarity is vital where diodes are concerned.

More or less the same approach applies to the circuit in figure 3, except that the box will need to be larger, and access will be required to both R3 and R6 for calibration.

The probe requires a bit more thought, as it is fairly fragile. It must be possible to bring the diode itself into contact with the object under test. **Figure 4** shows the arrangement I used, but this does depend on having a piece of quarter-inch dowel and an odd bit of rigid plastic tube (the classic one is the body of a used coloured felt-tip marker) that is just a snug fit on the dowel.

Cut two shallow grooves on opposite sides of the dowel, just deep enough to accommodate the wires from the diode. These should be bent at right angles to the diode body as shown in figure 4. Solder a length of flexible twisted pair (it will be necessary to make little dents or notches in the dowel to take the soldered joints). It should then be possible to slide the tube over the assembly as shown, leaving an inch or so of dowel protruding.

The advantage of this arrangement is that the plastic tubing can be slid down over the diode when the device is not in use.

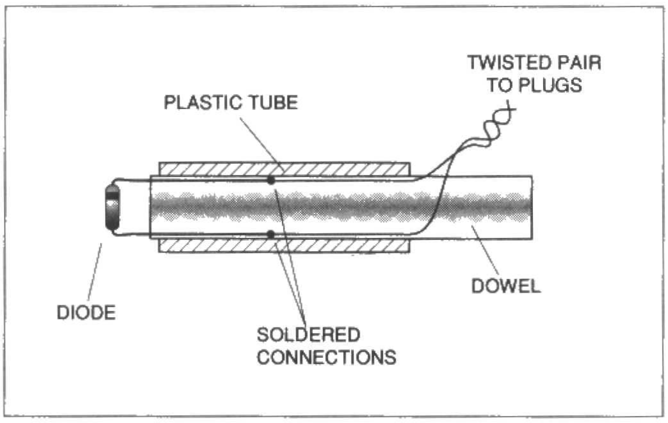


Figure 4: the arrangement of a small diode, 0.25-in diameter dowel and recycled plastic tubing to make up a probe tip

Calibration

To be really scientific some distilled water is required for this step, but for the accuracy we have, normally tap water will do, unless it is very heavily loaded with salts.

The process is quite simple. First put a few lumps of ice in a cup and stir until the ice just starts to melt. Once there is sufficient liquid present (not much), just dip the probe into the water and, if using a DVM and figure 2, note the voltage reading. If using figure 3 and a meter, adjust R3 until the meter reads zero. Be careful not to touch the ice during this step as it will be noticeably below zero.

For the other end of the scale, boiling water is needed. Now is a good time to be careful: not only is boiling water hot, but the steam is too. I found it was most easily done by boiling up an electric kettle and then lowering the probe by means of its (long) lead so that it just dips into the water. But is this means removing the kettle lid when it has just boiled - be careful, or you will end up with scalded fingertips! Again, if using figure 2 and the DVM, note the reading. For figure 3, adjust R6 until the meter just reads full scale.

The rest is straightforward: for figure 2 and the DVM, draw a graph for temperature against voltage, which should be a straight line, and then in future any temperature can be read off from the graph given the voltage.

For figure 3, the temperature is directly proportional to the scale reading: zero degrees C at one end and 100 degrees C at full scale.

Application 2

The previous application used the variability of the voltage across the diode with temperature. This application contrarywise looks upon the voltage as fixed, providing that the series resistance R in figure 1 is small.

We can use this feature to build a device which will indicate whether a current flow is present or not, and this in turn leads to a device which will confirm that everything is switched off, for example, on leaving the shack at night before locking up. The problem here is to get a "detector" which will on the one hand detect currents down to a few milliamps, to tell whether anything is still switched on, but at the other extreme will not be upset by large currents taken by heating appliances or similar. There is a further complication, known as "inrush current". Assuming a 240 volt mains supply (for instance), a 100-watt bulb by definition will take 100/240 = 0.42 amps in the steady state. However, the resistance of the cold bulb will be around 40 ohms, so the starting current will be 6 amps. The resistance of a 150-watt bulb is about 25 ohms, giving nearly 10 amps! The simple answer - to put a resistance in series with either the live or neutral, and measure the voltage across it - it not sufficient in this case, because of the wide variation in current. What is required is a constant voltage device so that, whatever current is flowing through it, the voltage across it does not vary by much. This brings us back to the diode.

Returning to figure 1, Vs is around 600mV and varies by about 2mV per degree Centigrade, so for temperatures from say -10 to +35 degrees C this is a change of only 90mV, which is too small to affect this application. Consequently in the configuration in **figure 5**, providing that a load is connected, about 600 mVAC peak would

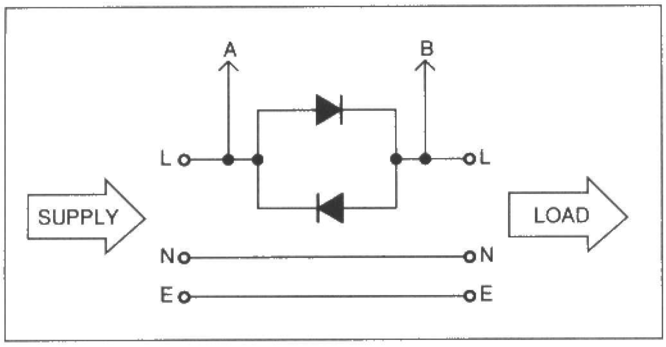


Figure 5: about 600 millivolts AC would appear between points A and B

appear between points A and B. We must of course use two parallel diodes in opposition to allow for the alternating voltage, and the plan will be easier to implement if we could allow a bit more than 600 mV, so we can double up on the diodes as in **figure 6**. The next step in the argument is to use a bridge rectifier (in effect, four silicon diodes in one moulding. It is cheaper that way, too) as shown in **figure 7**. The positive and negative terminals are connected together and the AC terminals used as the external connections.

Figure 8 shows a circuit for the device which will tell whether current is being consumed, and would be useful for the shack or workshop, with appropriately coloured LEDs, to indicate whether anything may have been left switched on. It could also be useful in a different situation as a warning device, for instance in an electrically heated greenhouse. Reversing the LED colours and arranging the device so that the LEDs are visible from the outside, the green light would indicate that all is well, a red light would indicate that the heating is on and will be expected to go off after a while, and no light at all says 'panic, the mains has gone off'.

The first important point is that the bridge rectifier must be related to the likely maximum current consumption, including the likely maximum fault current. If it is to handle all the shack load, then probably diodes of 25 amps minimum will be best. They will tolerate any fault condition that will rupture the standard in-plug 13 amp fuse, as well as supporting a heater, lights and equipment.

If a high current is to be used, the dissipation of the diodes must be accounted for. If 25A is flowing, the bridge rectifier may dissipate around 35W. A large heatsink may be required.

In **figure 8**, the earth and neutral connections go straight through from supply to load while the live is interrupted by the bridge rectifier BR1. I feel that it is intrinsically safer to have the bridge in the live, so that if for any reason it does fail the load is left with the live disconnected. **There must be a fuse between this device and the mains supply**. Whether this is in the workshop or elsewhere doesn't really matter, so long as it exists. In my case it is in the house prior to the feeder across to the shack.

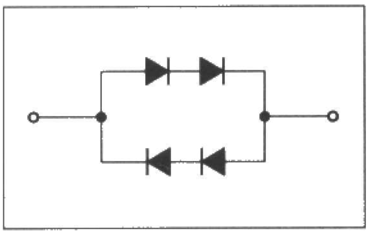


Figure 6: to allow a little more than 600 mV, the diodes are doubled up

This and the following application are mains-operated circuits and must be built and installed by a person with the required experience.

For my convenience, I have drawn the circuit with the common line for the electronics at the bottom, apparently upside down, that is, with the live at the bottom and the neutral at the top, because to me it seems easier to understand this way.

Now back to the beginning of the circuit. C1 operates as a voltage dropper. Being reactive, this consumes no power. The two resistors R1 and R2 limit the peak current at switch-on as follows: imagine, as a worst case, the unit being connected to the supply at the instant in time when the voltage was at a maximum of 350 volts (the peak voltage of a 240 volt supply). There is as yet no voltage across C1, so without R1 and R2 the current would only be limited by the forward resistance of the diodes which would almost certainly finish them off! R1 and R2 in parallel are 2350 ohms and so the mains voltage (350) will appear across them, which will limit the current to 350/2350 amps, or about 150 mA. This current only lasts for the odd few microseconds while C1 charges, so preventing any damage to the other components. Thereafter an alternating current of approximately 16 mA flows through the capacitor.

During the half-cycle when the live is positive, D1 conducts and neither of the LEDs are lit as they are reverse biased. D1 is necessary to prevent a large voltage appearing which would cause break-down of the reverse biased components. During the other half-cycle (the neutral is positive) and without any load connected, LED1 and D2 conduct so LED1 is lit. If now a load is connected, current will flow through BR1 at about 1.5 volts AC will appear across it. This is half-wave rectified by D3 and C2 so that about 2 volts are applied to R3 and Q1. Q1 turns on and current now flows through LED2 which will light. However, the voltage across the LED2/Q1 combination will be less than the forward voltage required by LED1 and D1, so LED1 goes out again. So the red LED2 is lit and the green LED1 is dark so long as there is a load connected. Upon disconnection (switch off) of the load Q1 turns off and the green LED comes on again.

PARTS LIST for figure 8

Components

R1, R2	4k7 0.5 watt or metal film 0.6 watt
R3	1k any type
C1	0.22u must be X type, rated at 240 VAC continuous
C2	47u 12V
Q1	NPN BC547 or similar
D1 - 3	1N4001
BR1	25-amp bridge rectifier.
LED1, LED2	2 x standard LEDs, green and red

Construction

The circuit in figure 8 can probably be built from ready-to-hand components, apart from BR1. One or two reminders may not come amiss. The box must ensure that heat from the rectifier is dissipated, and it must be electrically safe. Assuming that it will be mounted on a wall near where a mains outlet is available, preferably fairly high up, at eye level or higher, then a strong metal box is the most attractive solution, **but the box MUST be earthed. The earth wire should be connected to the metal case firmly, using an earth bolt not used for any other purpose. The lid of the case should be grounded similarly, using a wire attached to the same bolt using a second nut.** The box must be large enough so that the works are not cramped up inside, causing a danger of overheating or short circuit in the future. **It is always good practice with mains to install a sheet of strong plastic between the underside of the circuit board and the surface it is mounted on as further insulation, and doubly important to make sure that the board is mounted such that no component leads or solder joints or other live item can touch or puncture the plastic or contact the box.**

The heat from the rectifier can easily be calculated, as there will be about 2 volts across the bridge rectifier BR1 when on load. Allow for your expected highest total load, and multiply the current it represents by two to get the power to be dissipated by the bridge. As an example, allowing 2 kilowatts for heating and half a kilowatt for instruments, lights and so on, the total load would be 2.5 kilowatts. Represented by a current of 2500/240 amps, giving 10.4 x 2, near enough 21 watts. A substantial diecast box will be capable of getting rid of most of this if the bridge rectifier is bolted to the box with a smear of heat sink compound between them.

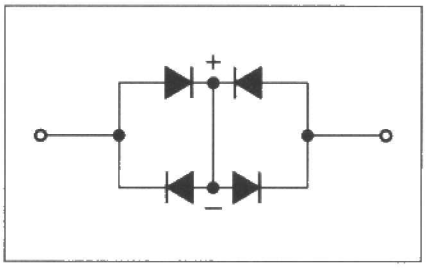


Figure 7: a bridge rectifier: a four-diode configuration

It is a very good idea to space the box away from the wall so that the rear is ventilated. The spacing can be quite small, something like half an inch at the most.

The electronics can be built on matrix board (such as Veroboard) and mounted inside the box along with two three-terminal choc-blocks, one for supply and one for load. Provide holes and grommets for the input and output cables, and fit the bridge in such a way as to allow for the addition of a heat-sink outside the box if necessary. It goes without saying that any metal bolts used to support heavy components must be double-checked to make sure that they cannot contact any live part inside the box under any circumstances, including the unit being inadvertently disturbed or dropped. **Figure 9** suggests a possible layout, but variation is possible so long as safety and heat dissipation are satisfied. It is probably best to construct the Veroboard/PCB first and then arrange the rest of the components to establish the size of box required.

It is envisaged that this unit will be fitted in a permanent position, for example connected to a freezer or plug distribution board. In that case, the unit should be fitted in series with the power lead of the appliance. The fuse in the unit's mains plug will prevent the current from exceeding 13A for long. It is not designed to be wired permanently to a 30A ring main, and such use would be unsafe.

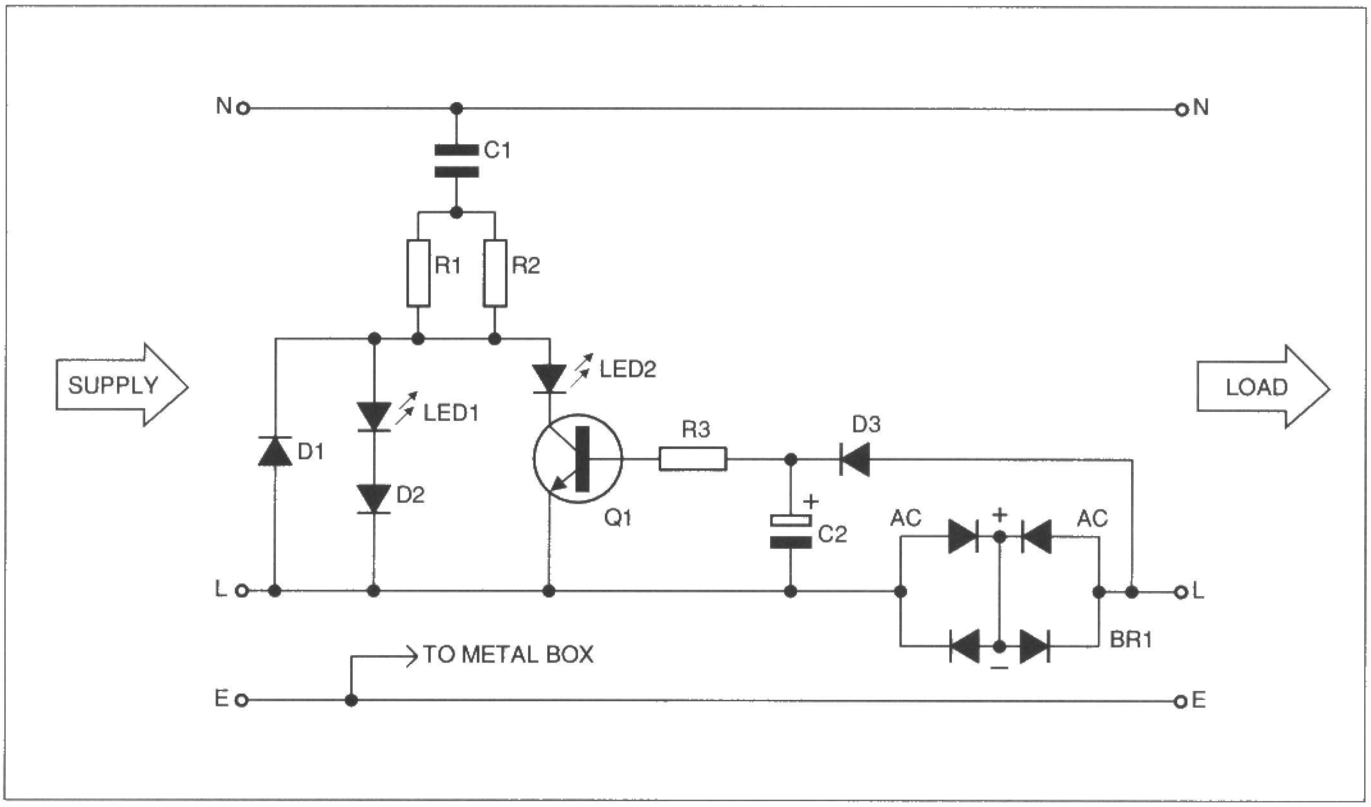


Figure 8: the circuit of a load-on indicator. Note that this circuit is drawn with the Neutral (N) line at the top. See the text for parts list and component values

Application 3

This is a variation on the previous theme such that a red LED is ON while the supply is on, and when a load is applied the mains is switched on to an auxiliary pair of terminals, instead of a green LED being lit.

For example, switching on one piece of kit can automatically switch on others. Or a mains-driven hour meter could be connected to the auxiliary terminals with the result that whenever the load is applied (switched on), the hour meter will run. This enables the time for which the load has been connected to be recorded in hours (usually in tenths of an hour as well). The device can be made up in a box with a 13-amp plug and lead for connection to the supply and a 13-amp socket for the connection of the load. An hour recorder may be built into the box or kept as a separate unit and connected by plug to a socket on the box. Mains operated hour recorders can be obtained in various forms from components suppliers such as RS, Electromail or Maplin, and usually have 6 or 7 digits plus tenths of an hour. Alternatively, they can be constructed from appropriate slow speed motors driving mechanical counters obtained from other equipment. Or you can use an ordinary clock to record up to 12 hours.

In this application the bridge rectifier doesn't have to be quite so beefy, with size depending on use. For instance, a 2-kilowatt heater takes about 8 amps and so in this case a 10-amp bridge would be adequate. Some major mods to the circuit in figure 8 will give the circuit in **figure 10**, which will achieve this objective. The arrangement on the right hand side of the figure is the same as before. The voltage across BR1 when a load is connected turns on a transistor, now Q2, via D3, C2 and R4. However, the left hand side is different. C1, R1, R2 and D1 are the same as before and serve the same purpose. With no load connected, Q2 is off and D2 operates as a rectifier keeping C2 charged. This positive charge via R3 keeps Q1 turned on which effectively shorts out pins 1 and 2 of IC1. LED1 is lit via Q1. IC1 is an opto-triac and since the opto bit (pins 1 and 2) is shorted out, the triac between pins 4 and 6 is non-conducting and no voltage appears at the auxiliary terminals. If the load is switched ON, the situation is reversed. Q2 is turned ON by the voltage across BR1, which in turn bypasses the base current of Q1. Thus Q1 is now OFF and the current through the LED1 also passes through the led within IC1. The triac portion thus conducts, connecting the live line to the auxiliary terminal. The full mains voltage therefore appears at the auxiliary terminal, and the hour meter, or whatever is connected, will operate.

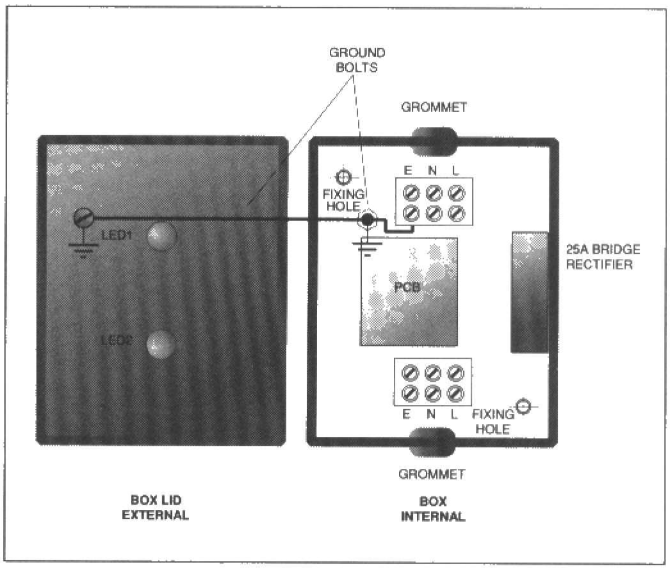


Figure 9: a suggested case layout for load-on indicator. See the text for box and connection information

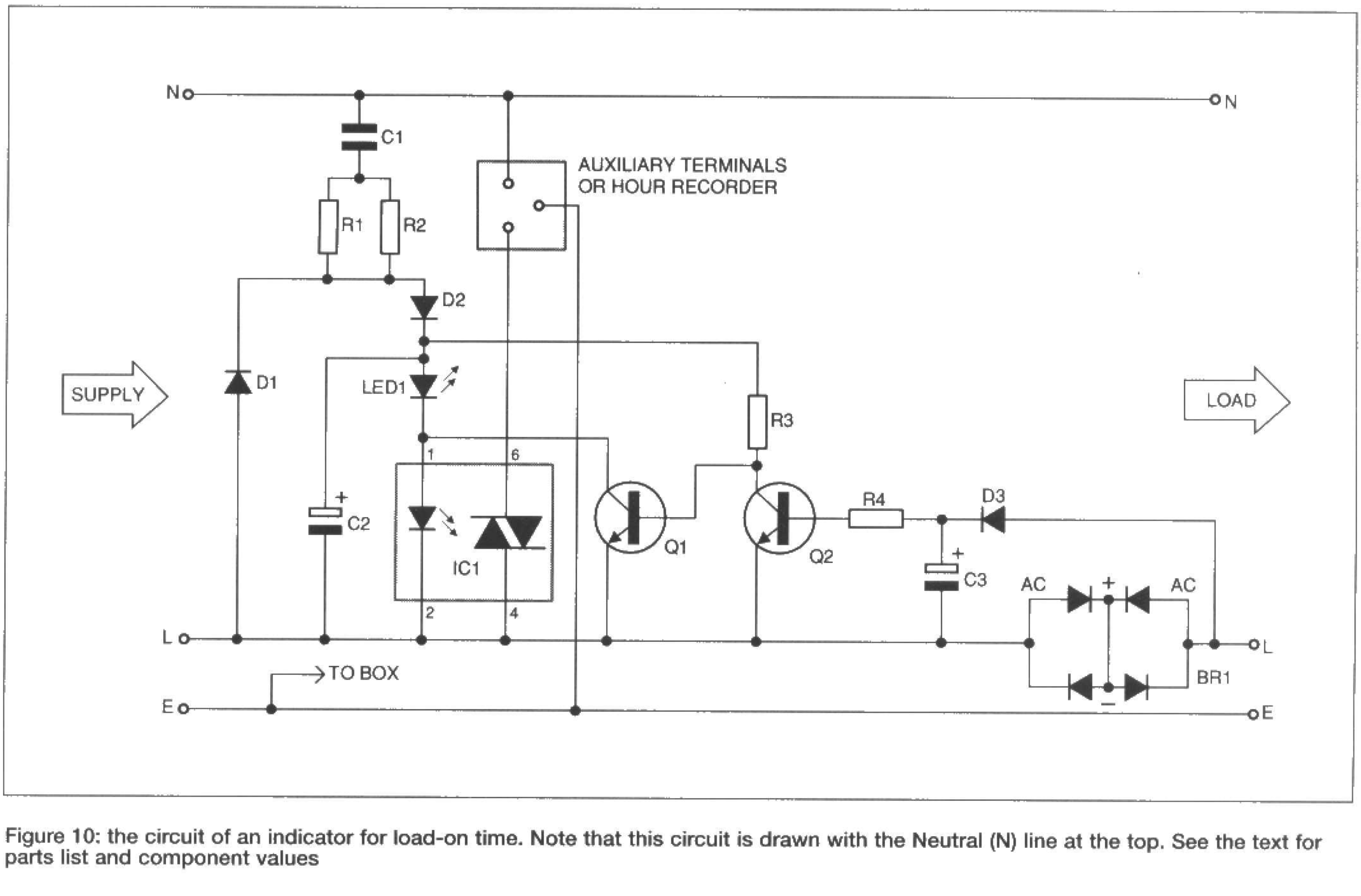


Figure 10: the circuit of an indicator for load-on time. Note that this circuit is drawn with the Neutral (N) line at the top. See the text for parts list and component values

PARTS LIST for figure 10

Components

R1, R2	4k7 0.5 watt or metal film 0.6 watt
R3	10k any type
R4	1k any type
C1	0.22u must be X type, rated at 240 VAC continuous
C2	100u 12V
C3	47u 12V
IC1	MC3020 opto triac
Q1, Q2	NPN BC547 or similar
D1-3	1N4001
BR1	Bridge rectifier. See text.
LED1	Standard LED red

Construction

The circuit in figure 8 was intended for permanent mounting, whereas the circuit in **figure 10** is really intended to be mobile and fitted with a plug and lead for connection to the supply and a socket for the connection of the appliance (load). It may also be designed with a built-in hour meter or with the hour meter as a separate item, in which case a connection socket will be required. If a connection socket is used, I would suggest that it is NOT a 13 amp socket, so that there is no chance of a heater being plugged in to the output of IC1 - which definitely wouldn't stand it. The maximum current is 100 mA. If this is not sufficient, then a relief triac must be added to IC1 to handle higher currents. **The hole for the incoming cable must be fitted with a strain relief and protective sleeve for the incoming cable rather than just a grommet. Figure 11** suggests a possible layout, though again there may be personal variations as necessary again so long as the heat dissipation and safety factors are looked after. Again build up the Veroboard/PCB and assemble the other components to assess the size of the box. Because this box will be larger than the one described previously, to allow for the 13-amp socket, it is unlikely to need a heat sink, but it would be a good idea to calculate the heat dissipated. **The box must be earthed as before, using earth bolt connections on the box and lid.**

Finally, a reminder. Mains projects must be made electrically and thermally safe - safe from touch, and safe from overheating. Make sure your mains constructions are suitably earthed, and that you have used heatsinks where required. Check solder joints with the greatest care, use strain relief grommets on mains-carrying cables, and solid connector blocks, and make sure that there is no strain on the Earth line where it is connected. Always mount your Veroboards/PCBs in the casing with insulating materials such as nylon bolts or standoff pillars, not metal bolts. Any metal bolts used to support heavy offboard components such as heatsinks must not be close to any live areas in the box, and the box must be large enough to allow for this. Remember that you may be using the device for many years to come, and its construction must be such as to stand the test of time. Safety first!

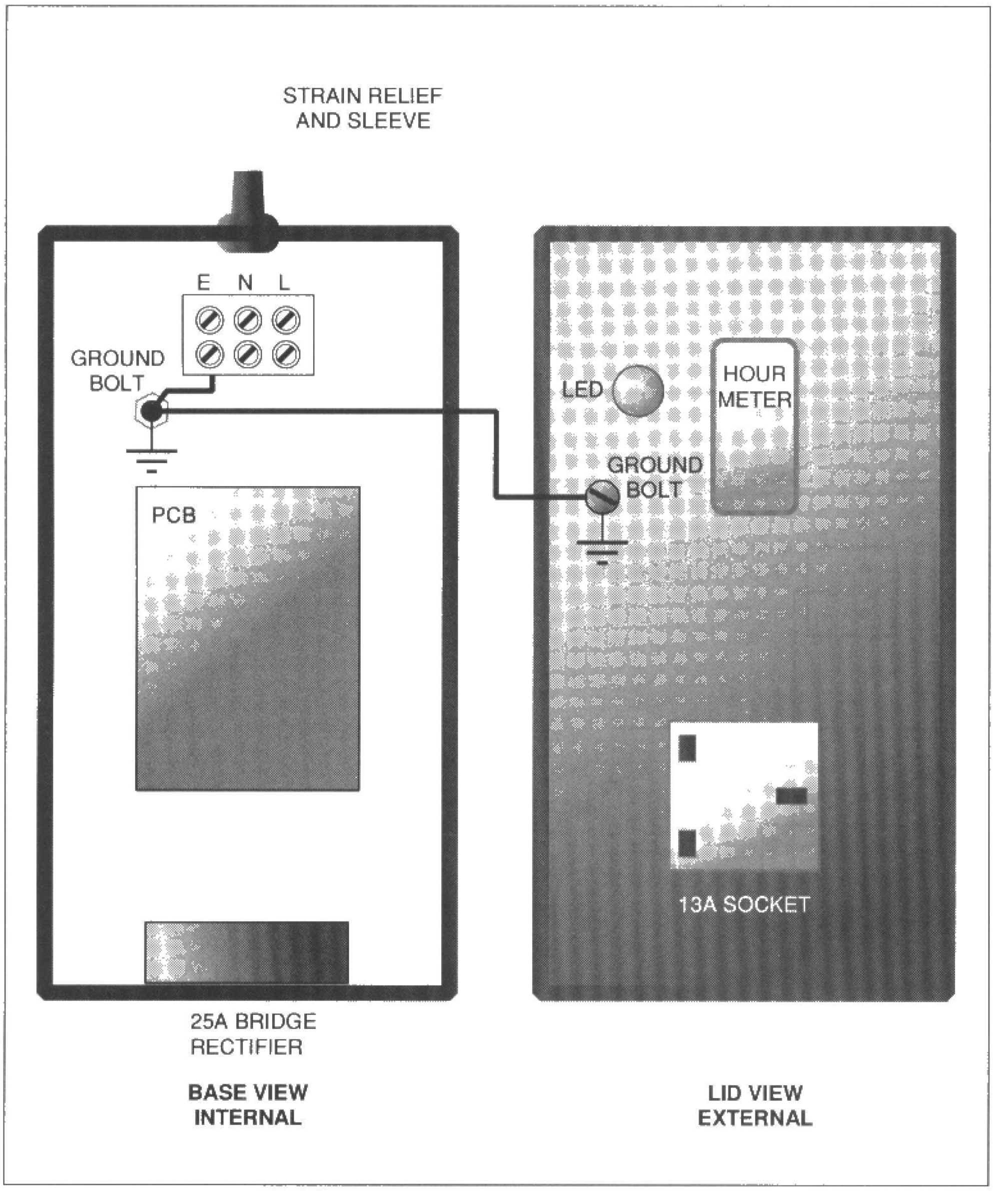
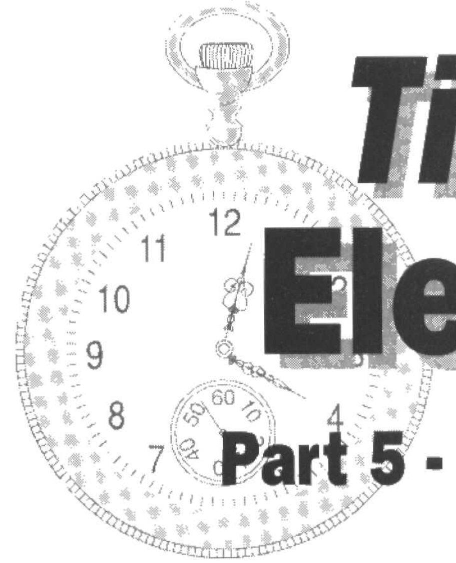


Figure 11: a suggested case layout for load-on time indicator. See the text for box and connection information



Timing in Electronics

Part 5 - Starting and Stopping

Owen Bishop

This month we concentrate on starting and stopping the clock, both in theory and by way of two practical timing projects.

We do not usually start and stop the clock itself. This is allowed to 'tick' steadily on, perhaps at one pulse per second. Its signal goes to a gating circuit, and we either open or shut the gate to let the signal through or to prevent it from going any further. **Figure 1** is one of the simplest gating circuits, using a NAND gate. Reference to the truth table for NAND (**table 1**) shows that the gate is enabled (passes the signal) when the enable input is made high. The gate inverts the clock signal. This is a fact that may make no difference to the operation of a timing circuit, but should be borne in mind, just in case it does. It is possible to build a similar circuit based on a NOR gate.

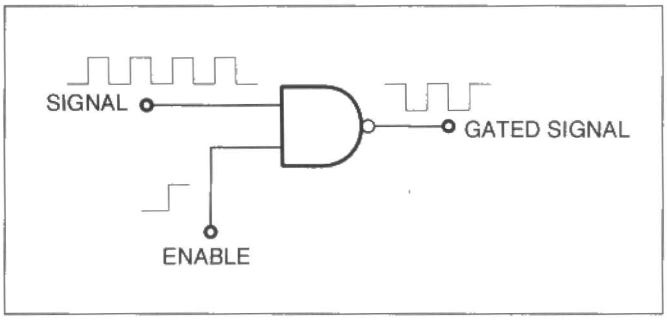


Figure 1: using a NAND gate to enable the clock signal

Table 1: Truth table for 2-input NAND logic

	Inputs	Output
A	B	
0	0	1
0	1	1
1	0	1
1	1	0

Gating can be done also with AND gates, OR gates, and transmission gates, none of which invert the signal. Most often we use NAND or NOR for gating because there are often spare gates of these types left over from other sections of the circuit.

Figure 2 illustrates a disadvantage of the single-gate enable. This applies whatever gate type is used, but we use an AND gate in this example to avoid confusing the description by having the signal inverted. An AND gate receives a clock input (top line) and an enable input (second line) and produces a gated signal. In Figure 2 the gated signal (third line) follows the clock when the enable is high. Usually the enable signal is triggered by an event in the outside world. Its timing bears no fixed relationship to that of the clock. We say that it is asynchronous. A problem arises if the enable goes low while the clock is high. This can be seen at the count of 5. A short pulse is produced because the gated signal inevitably goes low when the enable goes low. In our example there are two enabled periods, one lasting 4.2 clock periods and one lasting 2.5 clock periods. There is another short pulse at the beginning of the second period. The same problem arises with all single-gate circuits.

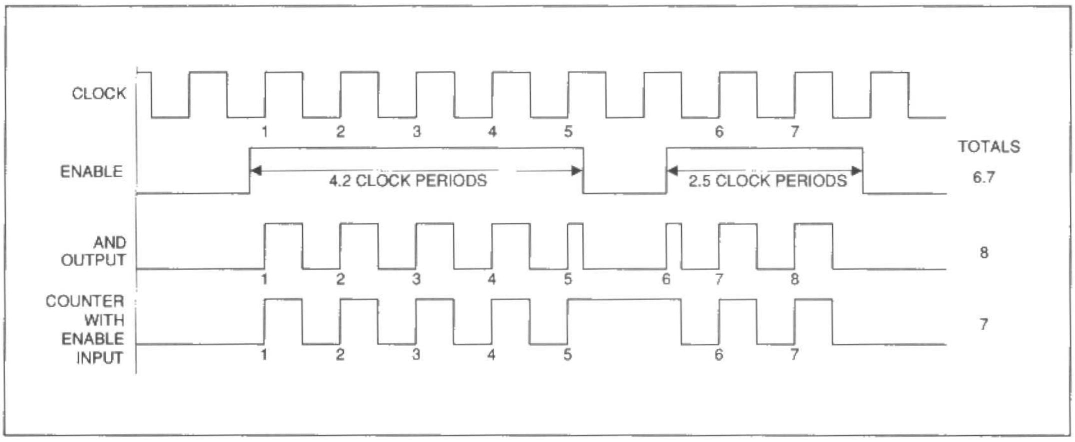


Figure 2: a single-gate enable circuit can generate an extra pulse

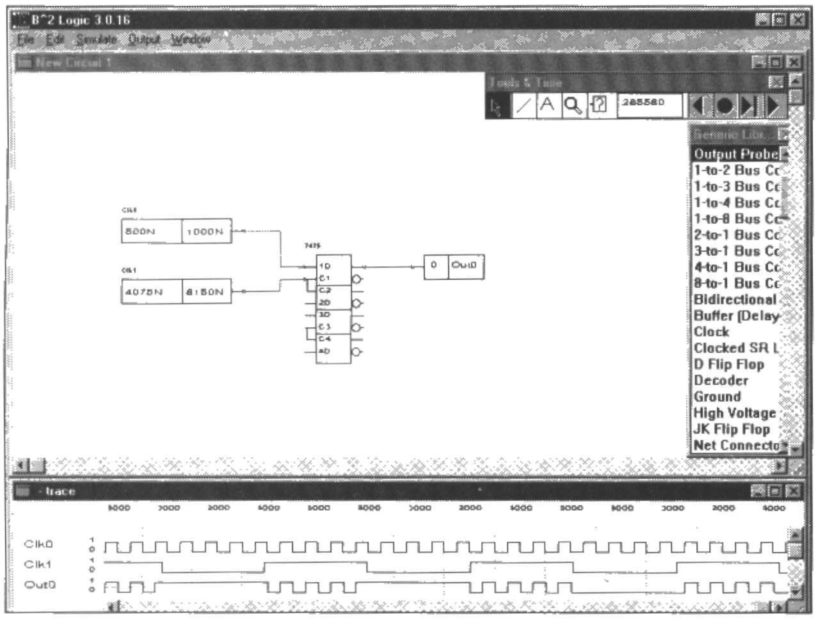


Figure 3: a latch ic does not generate an extra pulse when disabled

Suppose that the signal is next fed to the beginning of a counting chain, which is incremented on the positive-going edges. The total enabled period is 6.7 s, and the clock has 7 positive-going edges during that period. The count is a good approximation to the actual total timed period, since the resolution of the circuit is 1 s. But the output from the AND gate has 8 positive-going edges. A counter connected to the AND gate counts 8 instead of 7. The AND gate has inserted an extra count because it had to go low at the end of the first enabled period. An extra count does not make much significant difference if there is a single long enable period of, say 200 s or more. For a shorter period the error is proportionately greater. Also, if we are totalling the counts for many short periods there is a progressive accumulation of false counts.

Unforced enable

What is needed is an enable circuit that does not force a change of state at the beginning or end of the enable period. Some counter ics (but not many) have a built-in enable function that is easy to use and produces no extra counts. The 4026 counter in last month's LED display is one such device, though we did not make use of its enable input at the time. The 4026 is enabled when there is a low level on its enable input and last month we wired this permanently to the 0V line. The bottom line in **Figure 2** shows the signal passed on to the counter from its enabling circuit (this assumes that the enable signal is the inverse of that shown in line 2). At the end of the first enable period, the signal is high and stays high. There is no short pulse. The signal goes low again on the first negative-going edge of the clock after the second enable period has begun. The total count is 7, as required.

Figure 3 shows how to use a data latch for enabling a counter without inserting extra counts. This is a run on the B2Logic simulator. In the figure, the data latch is a 74LS75 quad data latch, but the 74HC75 or the 4042 can be used instead. The 74LS75 and 74HC75 require a high input to enable the counting. The 4042 has a polarity input which is wired to high or low. If the enable (store) input is set to the same logic level as the polarity input, the data is latched (disabled), but it is enabled if the enable input is set to the inverse level. In the simulation the clock (Clk0) runs at 1 MHz (period 1000 ns), while the gating signal runs at 122.7 kHz. For this demonstration we have set the period of the enable signal (Clk1) so that it is not a multiple of the clock. This makes the phase relationship between them change, so that the enable goes low sometimes when the clock is low and sometimes when it is high. In the display at the bottom there are two instances in which the enable goes low while the clock is high. The output stays high. On the right, the enable goes low when the clock is low. The output stays low. No extra counts are generated.

To reset the counter to zero every time it is enabled, use the circuit of **figure 4**. The signal from the clock is fed to a 4026 decade counter. This is the kind that we used last month to drive a seven-segment numeric display. Its clock-enable input is controlled by a push-button. The input is normally held high by the pull-up resistor, but goes low and enables counting when the button is pressed. **Figure 4** also has a pulse generator, built from two more NOR gates. The output of this is normally low, but goes high for about 100us whenever it receives a falling input. This occurs when SW1 is pressed. The low output pulse resets the counter ready for timing to begin.

When operating the circuit of figure 4, SW1 is held pressed to enable counting. When SW1 is released, counting is disabled. But the pulse-generator is unaffected by a falling input, no pulse is generated and the counter is not reset at the end of the timing period. Having to hold the button pressed is a disadvantage if the period lasts for more than a few minutes. An easy solution is to use a toggle switch instead of a push

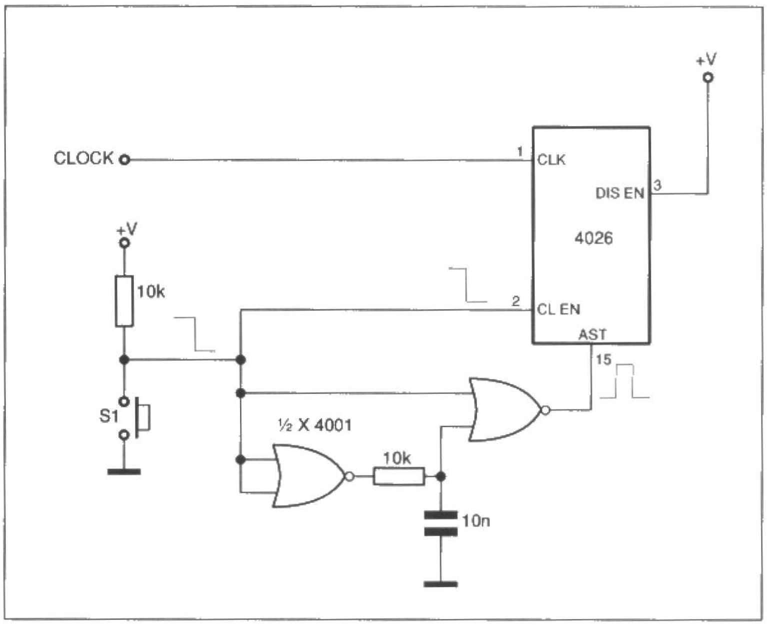


Figure 4: a circuit for resetting a counter and enabling the clock

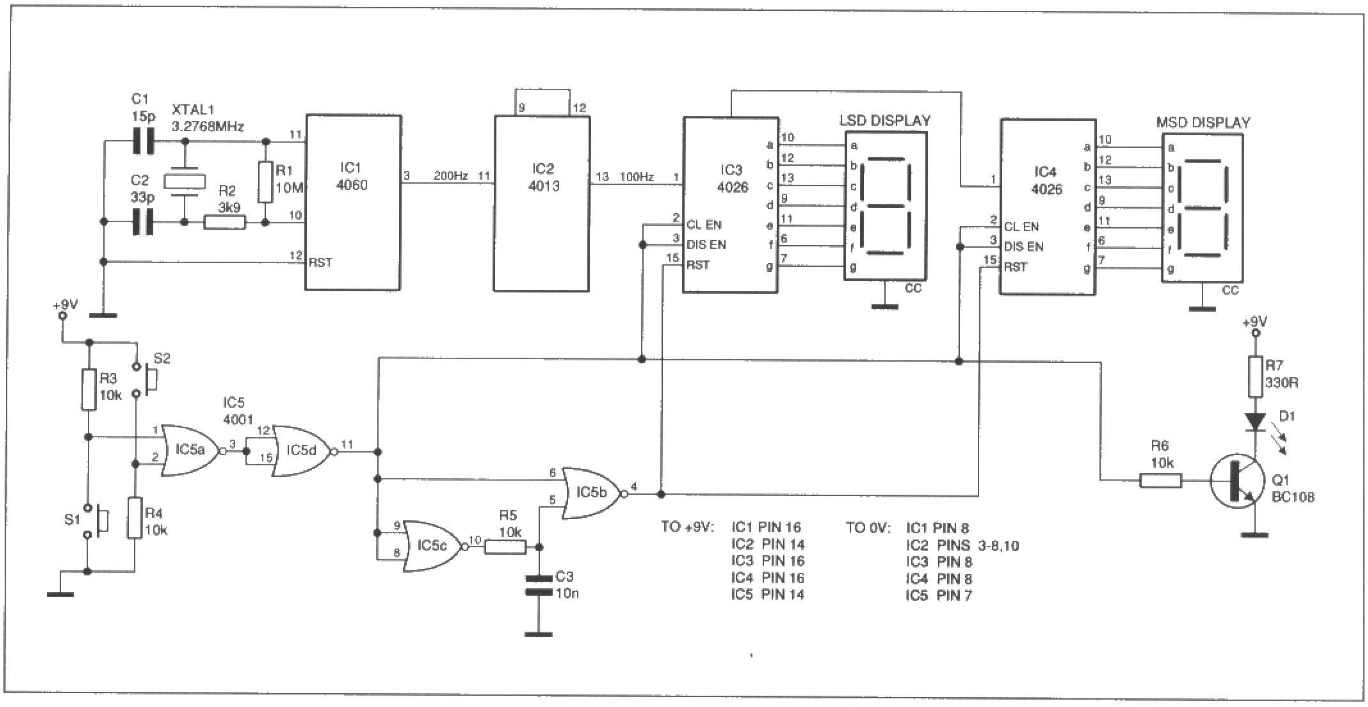


Figure 5: this circuit combines versions of several of our modules into a reaction timer and stopwatch

button. A toggle switch is just a plain on-off switch with a lever, which goes one way for 'on', and the other way for 'off'. Another solution is to use a push-button with a toggle action (push to turn on, push to turn off). This type is often found on table-lamps. There are many applications in which we want to time a period electronically instead of using a switch or button. An example of this kind of gating is given as the second practical project below.

Practical stop-watch and reaction timer

This is a clock which times events lasting up to 10 s with a precision of 1/100 s. It is built up of several of the circuits we have studied in previous parts of this series. Here we put them together on the same board to make a complete timer. It is just one example of the way that the basic circuit modules can be combined into a dedicated circuit. It can be either assembled by wiring together the individual modules or built on a single board.

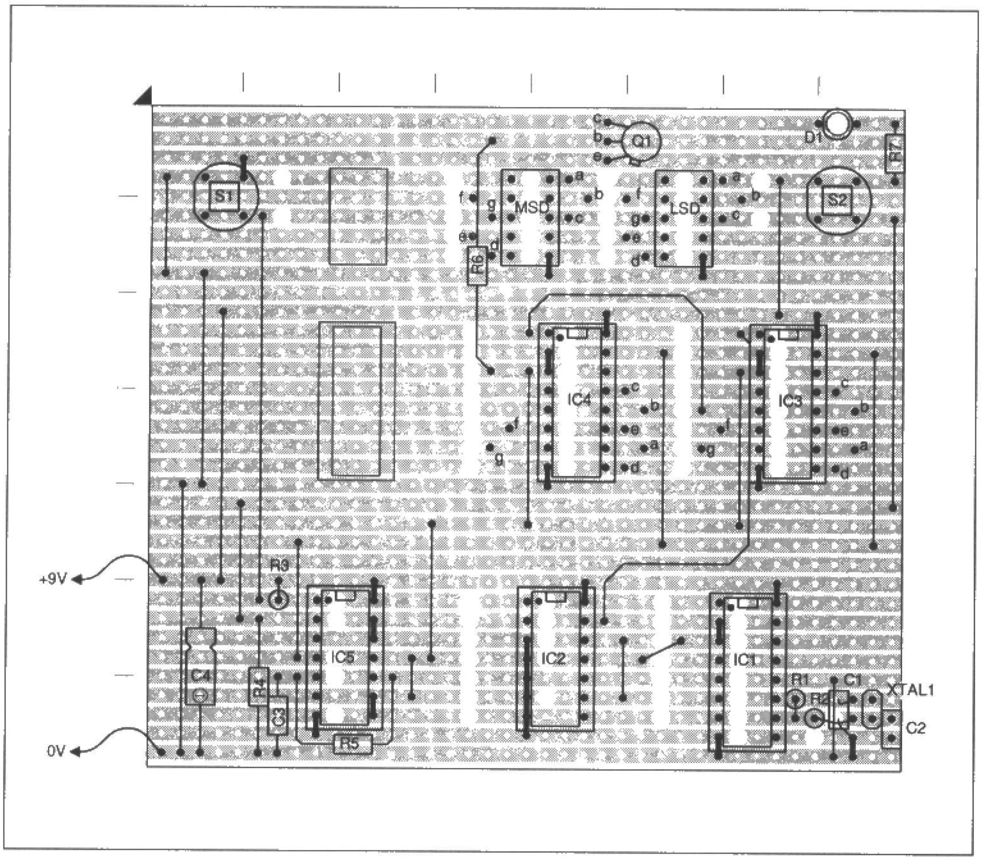


Figure 6: stripboard layout of the reaction timer and stopwatch

The clock is the crystal clock described in Part 2 (ETI 7/1998). To adapt it to driving a stop-watch we have made it run faster by using a 3.2768 MHz crystal instead of the 32.768 kHz crystal used in the earlier version. Dividing this count by 215 (as before) gives a 100 Hz signal from IC2. The LED is omitted because it would be flashing too fast to be of any use. The clock signal goes to a 2-stage counting chain with two LED displays. This is almost the same circuit as was used in Part 4 (ETI 9/1998). Now the clock signal is gated by a version of the circuit of **figure 4**. As in **figure 4**, there is a pulse generator to reset the counter at the beginning of the period. Because of the high clock rate, which makes it pointless to display the count while timing is in progress, the output from the gating circuit goes to both the clock enable and the display enable inputs. The inputs operate with opposite polarity. When the inputs are low, counting is enabled but the display is disabled. When timing

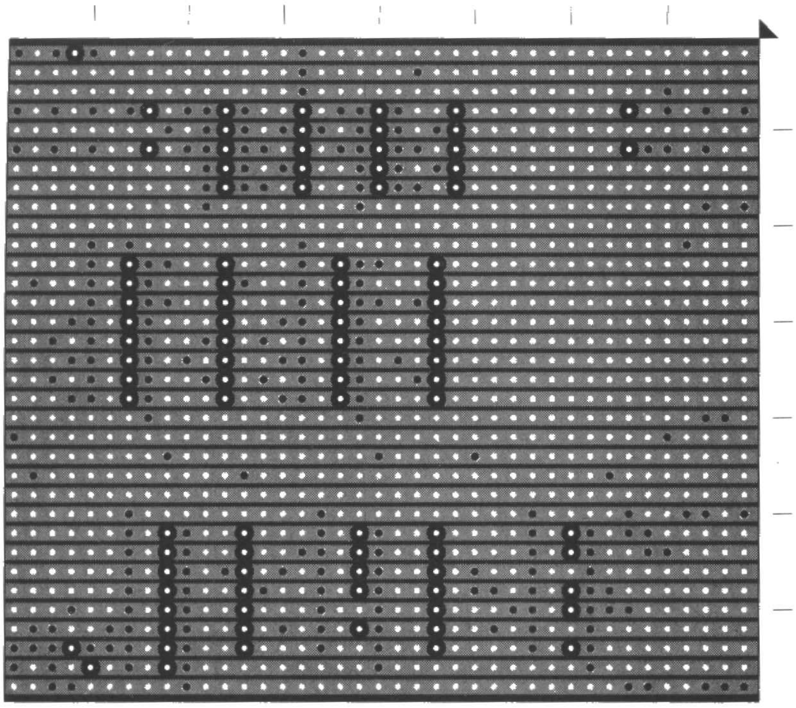


Figure 6F: the back of the stripboard showing cutouts

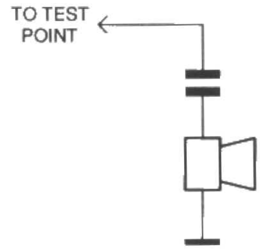
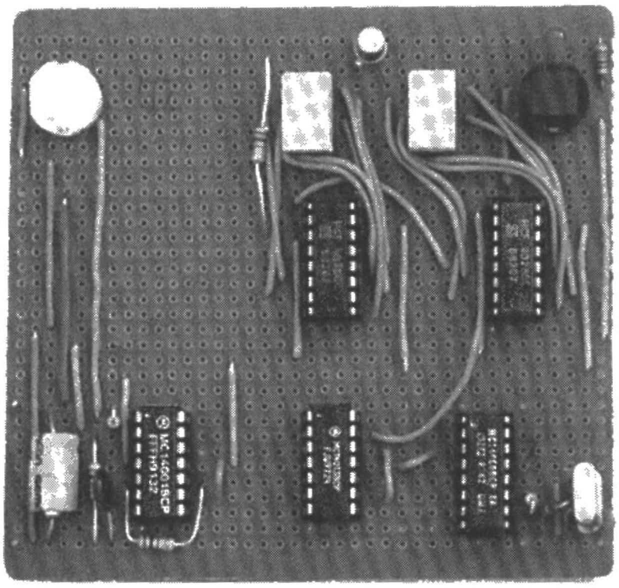


Figure 7: using an earpiece to check the output from the 100 Hz clock. The capacitor can have any convenient value

ends the inputs are made high to disable the clock and enable the display.

The input to the gating circuit is designed for a reaction timer. There are two buttons, SW1 being operated by the person running the test and SW2 being operated by the subject of the tests. Normally, the low and high inputs to IC5a make its output low, and the output of IC5d is therefore high. Counting is disabled, the display enabled and the indicator LED is on. When the operator presses and holds SW1, gate 5a has two high inputs and changes state. The clock is enabled, the display disabled and the LED goes out. The subject has been told to press SW2 as soon as they see the LED go out. When the subject presses SW2, gate IC5a changes state again, counting stops, the display comes on and the LED comes on too. The display shows the time in hundredths of a second between S1 being pressed (LED comes on) and SW2 being pressed. In other words, this is the subject's reaction time in hundredths of a second.

The same gating arrangement can be used when operating the circuit as a stopwatch. For short periods, the operator presses and holds SW1, releasing it at the end of the period. For longer periods it may be more convenient to fit a toggle switch instead of the push-button. SW2 is not used in the stopwatch and may be omitted. It may also be worth while to extend the counting chain and the display to three digits, enabling periods up to 9.99 s to be timed. Space has been left on the board (**figure 6**) to accommodate the extra 4026 and display.



Construction

Build the clock first (IC1 and IC2), and wire the 100uF electrolytic capacitor C4 across the power rails. Use an oscilloscope to check that the clock is working. Alternatively, connect an earplug temporarily to the outputs of IC1 or IC2 (**figure 7**) and listen to the 200Hz or 100Hz signal. Next, assemble the gating circuit (IC5) and check its operation. The switches shown are described as 'click-effect' because of the positive feel of their action. Any other type of switch may be used and you may decide to mount SW1 off-board so that the subject can not see when it is about to be pressed. Finally wire up the counting chain and displays. The wires joining the counter ics to the displays are marked by their ends (a to g) in figure 6. IC3 switches the least significant digit

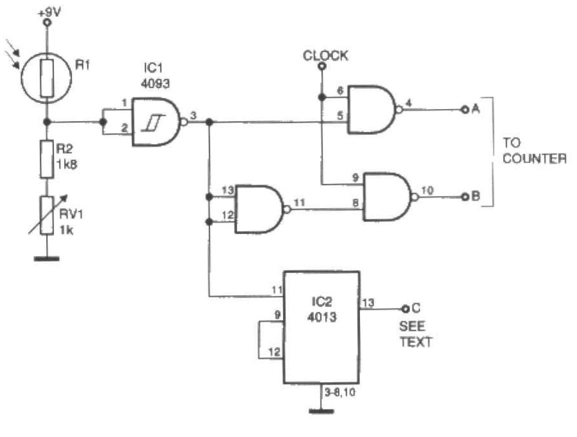


Figure 8: an electronic gating circuit deriving its action from a light-dependent resistor

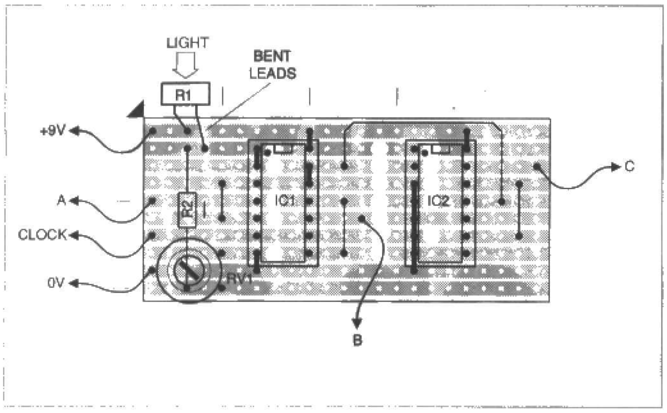
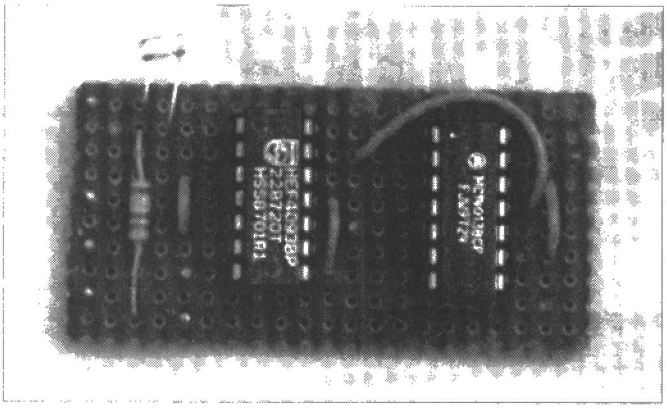


Figure 9: stripboard layout of the photosensitive gating circuit



(LSD). The displays are low-current types so that they can be driven directly from the 4026s. They must be common-cathode displays.

Electronic gating

Figure 8 is an example of the ways in which a stopwatch or other timing circuit may be gated as a result of an external event. The sensor is a light-dependent resistor. In average daylight its resistance is about 1 kilohms, and increases when it is shaded. Current flows through the resistor chain generating a potential difference across R2 and RV1. This voltage becomes the input of the NAND gate. We adjust RV1 so that the input voltage is a little more than 5V. This counts as a high input making the output go low. This NAND gate is special because, unlike the usual NAND gate of the 4011, this one has Schmitt trigger inputs. They have a rapid 'snap' action and, once the voltage has fallen sufficiently to change the state of the gate (at about 4.1V), the voltage must rise appreciably (to about 4.9V) before the gate changes back again. A slowly and erratically changing light level causes one and only one change of state, not a series of 'ons' and 'offs'. The result is a single well-defined timing period, with no false starts.

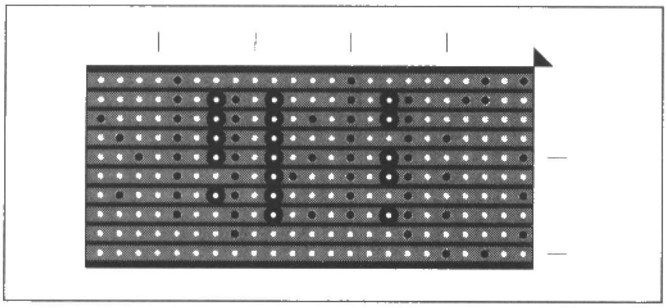


Figure 9F: the back of the stripboard showing cutouts

There are many ways of using light to trigger a circuit into action, so this circuit has many applications. You could use other sensors in place of the LDR, modifying the circuit accordingly. Examples are a photodiode, a thermistor, a Hall effect device, and a microswitch.

The circuit of **figure 8** has three outputs, two of which gate the clock directly. Output A produces the clock signal for as long as the LDR is shaded. Output B has the opposite action. There is also an output though a 4013 wired as a divide-by-2 flip-flop. The output of this is used to drive a resetting/enabling circuit such as that in **figure 5**, being connected in place of gates IC5a and d and the components to their left. The output changes state each time the LDR is shaded, even if only for an instant. As the output goes low it resets the counter and enables counting. At the next shading, the output goes high, counting ends and the time is displayed. This circuit can be used as a lap timer, particularly for model racing cars. A beam of light is aimed across the track at the LDR. Timing begins when a car passes between the source of light and the LDR, and ends the next time it passes the same point.

Practical lap timer

The LDR may be of any type, and the values of R2 and RV1 chosen to give an adjustable output between about 4V and 5V under average operating conditions. Omit any outputs you do not need, but remember to connect all unused inputs of the 4093 either to +9V or to 0V. If this is built as part of another circuit, only the gate connected to the sensor need be a 4093. The rest can be 4011s.

PARTS LIST

Reaction Timer and Stopwatch Circuit

Passive Components

R1	**10M**
R2	**3k9**
R3, R4, R5, R6	**10k**
R7	**330R**
C1	**15p**
C2	**33p**
C3	**10n**
Xtal 1	**3.2768 MHz**
SW1	**Pushbutton or toggle**
SW2	**See text**

Semiconductors

IC1	**4060**
IC2	**4013**
IC3	**4026**
IC4	**4026**
IC5	**4001**
Q1	**BC108**
D1	**LED**
2 x LCD displays	

Gating Circuit

All Components

R1	**Light-dependent resistor**
R2	**1k8**
RV1	**1k**
IC1	**4093**
IC2	**4013**

Computer Aided Design on a Shoestring

Using an everyday spreadsheet to simulate component interactions in a circuit design, using the spreadsheet's ability to do instant calculations.

John Howden

Circuits that I design at home usually start on the back of an envelope and are developed on a solderless breadboard. My latest project, a temperature meter, needed more powerful support tools.

The thermistor sensor that I planned to use had a non-linear response. I expected that this could be corrected, but I did not know what the correction circuit was, or how to calculate its component values. It was tedious to repeat "cut and try" resistor value calculations with a calculator. The breadboard was not much help, as I would need a set of reference temperatures to test every adjustment of the circuit.

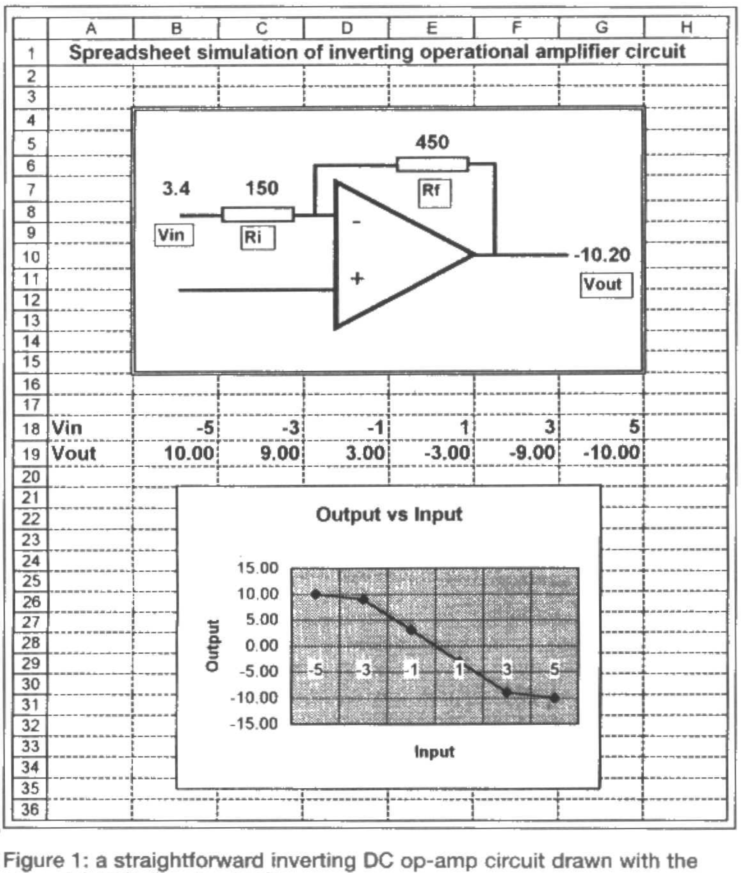
The ideal solution, of course, would be to have a Computer Aided Design package on my home computer. That way I could draw the circuit, simulate it and even produce the printed circuit pattern with a few clicks of my mouse. Back to the real world! The number of projects I undertake at home couldn't justify the cost at the time I was working on this, although I notice that the price of some packages have come down a great deal in the last year or so ... However, it gave me another idea.

I did have a computer with some general-purpose software packages: a word processor, a spreadsheet, and a desktop publisher - the same software that many computer users have. Maybe I could use these tools to do the job I needed? That was how it turned out.

Computer spreadsheets

First, I had to have a circuit design that worked. The spreadsheet was the obvious solution. You do not need an advanced spreadsheet to do complex linked calculations and plot graphs of sections of data. Even basic spreadsheets are particularly good at "what if" calculations, where the result of varying a data item can be seen instantly.

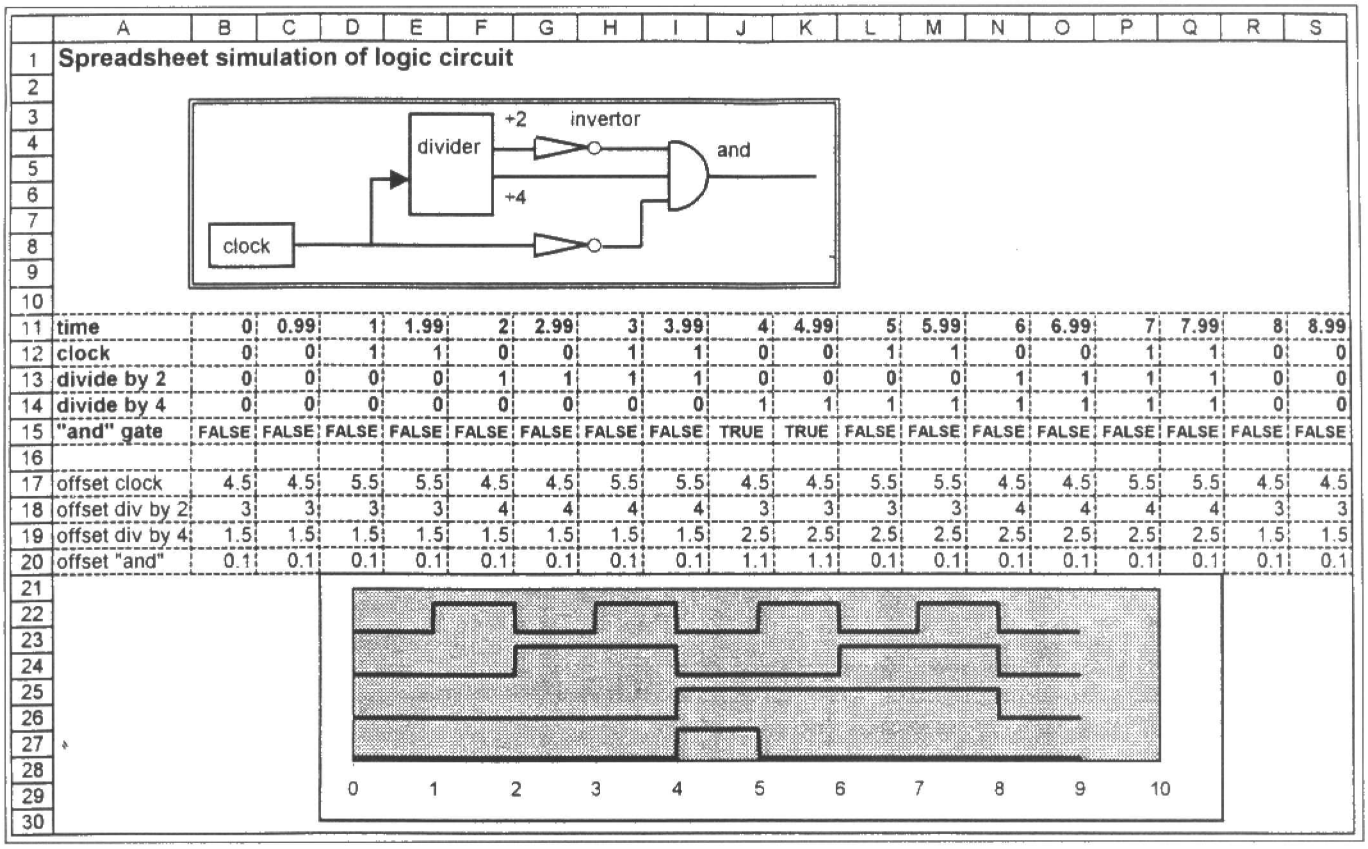
I think that a spreadsheet could be useful for designing any circuit that involves interaction between component values. Operational amplifier circuits, audio circuits, binary logic, filters and oscillators would be some examples. The spreadsheet could also be extremely effective for teaching. The ability to plot one parameter against another or to plot parameters against time and show an instant result should be especially helpful.



Spreadsheet simulation of inverting operational amplifier circuit

	B	C	D	E	F	G
Vin	-5	-3	-1	1	3	5
Vout	10.00	9.00	3.00	-3.00	-9.00	-10.00

Figure 1: a straightforward inverting DC op-amp circuit drawn with the spreadsheet's drawing tools



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
1	**Spreadsheet simulation of logic circuit**																		
2																			
3																			
4																			
5																			
6																			
7																			
8																			
9																			
10																			
11	time	0	0.99	1	1.99	2	2.99	3	3.99	4	4.99	5	5.99	6	6.99	7	7.99	8	8.99
12	clock	0	0	1	1	0	0	1	1	0	0	1	1	0	0	1	1	0	0
13	divide by 2	0	0	0	0	1	1	1	1	0	0	0	0	1	1	1	1	0	0
14	divide by 4	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	0	0
15	"and" gate	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	TRUE	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE
16																			
17	offset clock	4.5	4.5	5.5	5.5	4.5	4.5	5.5	5.5	4.5	4.5	5.5	5.5	4.5	4.5	5.5	5.5	4.5	4.5
18	offset div by 2	3	3	3	3	4	4	4	4	3	3	3	3	4	4	4	4	3	3
19	offset div by 4	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	1.5	1.5
20	offset "and"	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	1.1	1.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
21																			
22																			
23																			
24																			
25																			
26																			
27																			
28																			
29																			
30																			

Figure 2: plotting changes with time

There are naturally some limitations in using a spreadsheet to model an electronic circuit, and they are, indeed, much the same limitations as a dedicated circuit simulation package. Real components in the real world, even high-tolerance ones, rarely exhibit the ideal and sometimes over-simplified behavior expected by simulators. They have non-linearities, time delays, parasitic oscillations and other features that need to be dealt with if a circuit is to work. Prototyping still has an important role to play. Even so, a spreadsheet model could save a great deal of trial and error and increase understanding of the way a circuit is likely to behave.

Preliminary experiments were encouraging. I found, however, that it is easy to get confused when circuit values are represented by spreadsheet cells. As a minimum, the circuit needs to be drawn on paper, labels added and these labels used next to the appropriate cells. With the more advanced spreadsheets, such as Excel (the one I use myself), you can draw or import diagrams, and then enter data into the cells underlying the drawing. It is much easier to see what is going on when using a circuit diagram combined with spreadsheet cells in this way.

Applying a spreadsheet

A couple of simple examples will show how the spreadsheet might be used in practice.

Figure 1 shows a straightforward inverting DC operational amplifier circuit. The circuit was drawn using the spreadsheet's drawing tools. Some text was added with the drawing tool to identify the components, etc., but the actual values have been entered into cells on the spreadsheet. Thus "Ri" is a label but "150" is a constant in cell C7.

The spreadsheet cell G10, representing the output voltage Vout, is loaded with the formula for an inverting operational amplifier configuration:

Vout = - Vin * Rf / Ri

or in spreadsheet terms (Excel format) the cell contains "= -B7*E5/C7".

We can now manually vary the value of Vin to see what Vout should result or vary the resistor values to find a required Vout for a given Vin. For simplicity, the effect of saturating the amplifier output is ignored here.

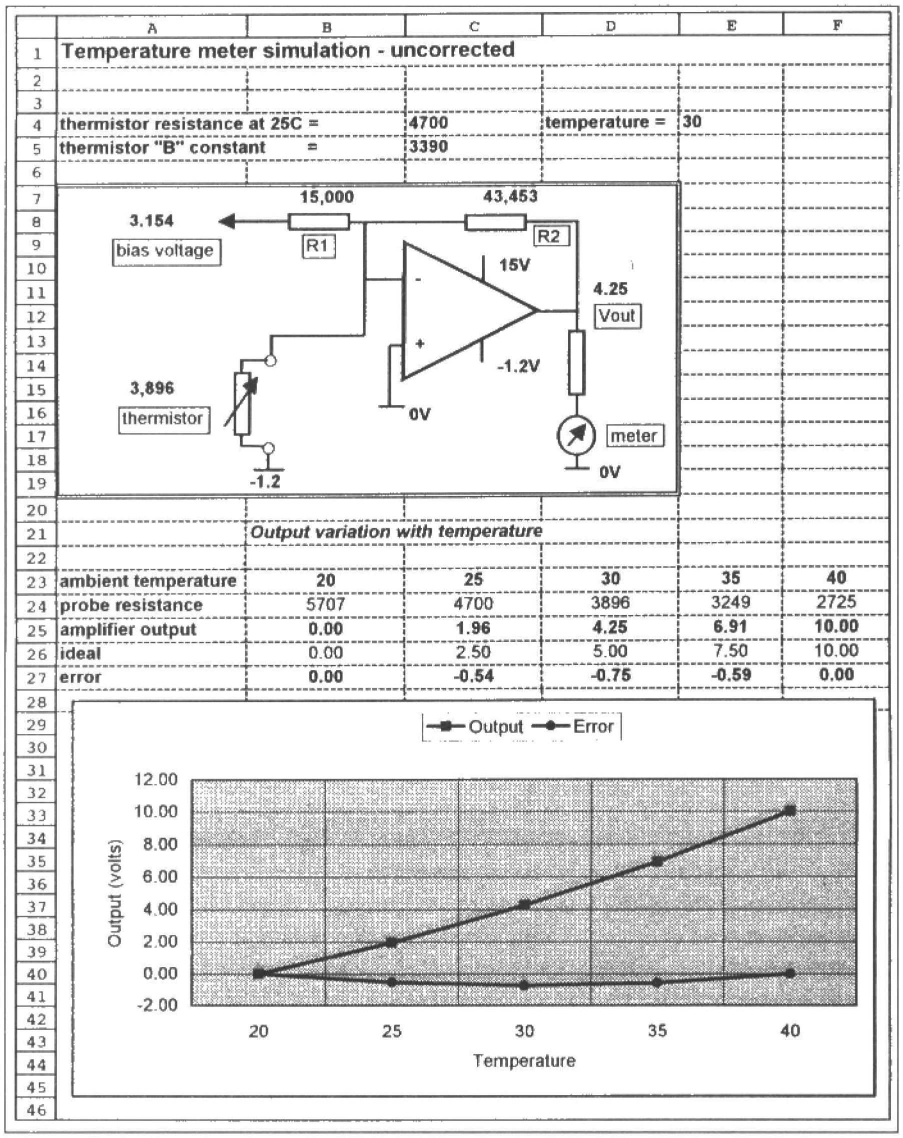
This calculating facility can be useful in itself as a teaching aid or when designing circuits with more complex mathematics. It is even better to use the spreadsheet plotter, perhaps to plot Vout against Vin.

This looks messier on the spreadsheet, since we need to set up a cell for each input value and another for the corresponding output value. Fortunately it is not as difficult as it seems, since it is easy to copy cells on a spreadsheet. Formulae are automatically varied according to grid position. We just need to ensure that the formula in the first cell of the row is correct. It must reference the other cells by absolute location or relative location as appropriate.

In the example, cells B18 to G18 have been loaded with the input voltage values to be displayed. For plotting purposes it is important that the steps should be regular if a "line" graph is used, else use an "X-Y" plot style. Cell B19 contains a modification of the formula in cell G10. The output is limited to the rail voltage, here assumed to be plus and minus 10 Volts. The input voltage must be taken from the cell above. So the formula is:

=-MIN(MAX(B18*$E$5/$C$7,10),-10)

Once the formula is satisfactory it can be copied to cells C19 to G19. The reference to B18 is automatically updated by the spreadsheet to C18 and so on. Absolute references, signaled



	A	B	C	D	E	F
1	**Temperature meter simulation - uncorrected**					
4	thermistor resistance at 25C =		4700	temperature =	30	
5	thermistor "B" constant =		3390			
21		*Output variation with temperature*				
23	ambient temperature	20	25	30	35	40
24	probe resistance	5707	4700	3896	3249	2725
25	amplifier output	0.00	1.96	4.25	6.91	10.00
26	ideal	0.00	2.50	5.00	7.50	10.00
27	error	0.00	-0.54	-0.75	-0.59	0.00

Figure 3: a practical thermistor example, but with the power rails offset to refer the non-inverting input to 0V to simplify the spreadsheet

by dollar signs, remain unchanged.

It can often help to do steps such as output limiting in stages. So we could have had two rows for Vout, the first containing the simple formula and the second applying the limits. This reduces the chances of making a mistake in the formula.

It remains to tell the spreadsheet to plot cells B18 to G18 as the x-axis and cells B19 to G19 as the y-axis of a suitable graph. Note that such graphs can be a little misleading; in this case the "3" and "5" points are linked with a straight line, which is incorrect. Plotting more points would make the graph more accurate.

A logical approach

Figure 2 demonstrates how changes with time can be plotted. The simple logic circuit shown comprises a regular clock pulse feeding a divider circuit. The divider has divide by two and divide by four outputs. The divide by two signal and the clock are inverted and fed together with the divide by four output into a logical "and" gate. We are interested in the behaviour of the output with time, which we can see by using the X-Y plotting facility on the spreadsheet.

One row of spreadsheet cells is set up to indicate time. Below the time cells we can place rows of the outputs from various parts of the circuit. There is a slight snag. The spreadsheet plot will simply connect one point to the next. To display a vertical edge we have to plot two Y points at the same, or nearly the same, X point. So instead of time points 0,1,2,3 etc. we need 0, 0.99, 1, 1.99 and so on.

Each signal is to be plotted against the time value on the x-axis. To separate the traces we need to set up yet another set of data cells which I have called "offset clock", "offset divide by 2", and so on. These contain the value of the appropriate signal plus a fixed offset. This offset is fairly arbitrary and is merely used to position the trace on the plot.

All this would seem to need a lot of effort. In fact, once the formulae in cells B12 to B20 have been set up, they are easily copied to the remaining cells to the right using the in-built power of the spreadsheet.

The formulae in the key cells are as follows:

B12 (clock)
=INT(MOD(B$11,2))
B13 (divide by 2)
=INT(MOD(B$11/2,2))
B14 (divide by 4)
=INT(MOD(B$11/4,2))
B15 ("and" gate)
=AND(B14,NOT(B13),NOT(B12))
B17 (offset clock)
=B12+4.5
B18 (offset div by 2) =B13+3
B19 (offset div by 4) =B14+1.5
B20 (offset "and")
=B15+0.1

The main signals are derived by suitable division of the time, followed by modulo two conversion (the remainder after division by two). The result is transformed into an integer, which should be either zero or one. These values are suitable inputs for the "and" function.

Design example: a temperature meter

Now for a more practical example based on my original problem (**figure 3**). For this article, I have modified the power rails of the circuit to make the spreadsheet easier to understand. In the real circuit, the operational amplifier supplies were 0V and 5V, with the non-inverting input and meter taken to a stabilised reference voltage of 1.2V. The thermistor was taken to 0V, which effectively put -1.2V across the thermistor.

As the temperature of the thermistor probe increases, its resistance decreases. This increases the current through the probe and hence the amplifier output voltage.

The adjustable bias voltage sets the meter to zero at the lowest temperature to be indicated. The maximum meter reading is assumed to occur at an amplifier output of 10V. Initially the bias voltage (cell A8) is adjusted by trial and error to obtain zero output when the temperature is 20 degrees. Resistance R2 (cell C7) is then adjusted to give Vout of 10V for a temperature of 40 degrees.

The thermistor is a miniature bead type from RS/Electromail.

According to a datasheet its temperature characteristic is represented by the equation:

R2 = R1 * e(B/t2 - B/t1)

Where:

R2 is the resistance at temperature t2
R1 is the resistance at temperature t1
B is the characteristic constant for the thermistor
t1 and t2 are the thermistor temperature in Kelvin

or in spreadsheet terms (cell A15):

`= $C$4*EXP($C$5/($E$4+273)-($C$5/(25+273)))`

This is modified slightly for cells B24 to F24, so that the t2 values are taken from cells B23 to F23 respectively. The cell that represents amplifier output voltage (D11) contains:

`= -(($B$19*$C$7/$A$15)+$A$8*$C$7/$B$7)`

Again, this is modified slightly for cells B25 to F25, taking the probe resistance from the cell above instead of from A15.

This time we plot two parameters on the graph: the output voltage and the output linearity error, both against thermistor temperature. The output is seen to be significantly non-linear. The challenge is to correct this.

I had a hunch that introducing a series resistor (R3) might have the desired effect. **Figure 4** shows the much-improved linearity after a period of trial and error changes to the value of R3. For each trial value the bias voltage and feedback resistance had to be re-balanced. Excel has a "goal-seeking" utility which makes this operation easier. It sets a cell value by dragging a graph point with the mouse.

I later refined the circuit by adding another resistor in parallel with the probe. The aim was to decrease the effective voltage across the thermistor and reduce self-heating effects. It was easy to demonstrate that this circuit change could be made without upsetting the linearity correction. The performance of the final design was confirmed by breadboard tests.

This example shows how a spreadsheet is much easier to use than a breadboard to find critical values in a circuit with interacting components.

Cheap PC layouts

Now that I had a suitable design, I wanted to prepare a printed circuit layout for the meter. A few experiments convinced me that I could use the drawing tools provided by a Desktop Publishing package to plot a single-sided track pattern.

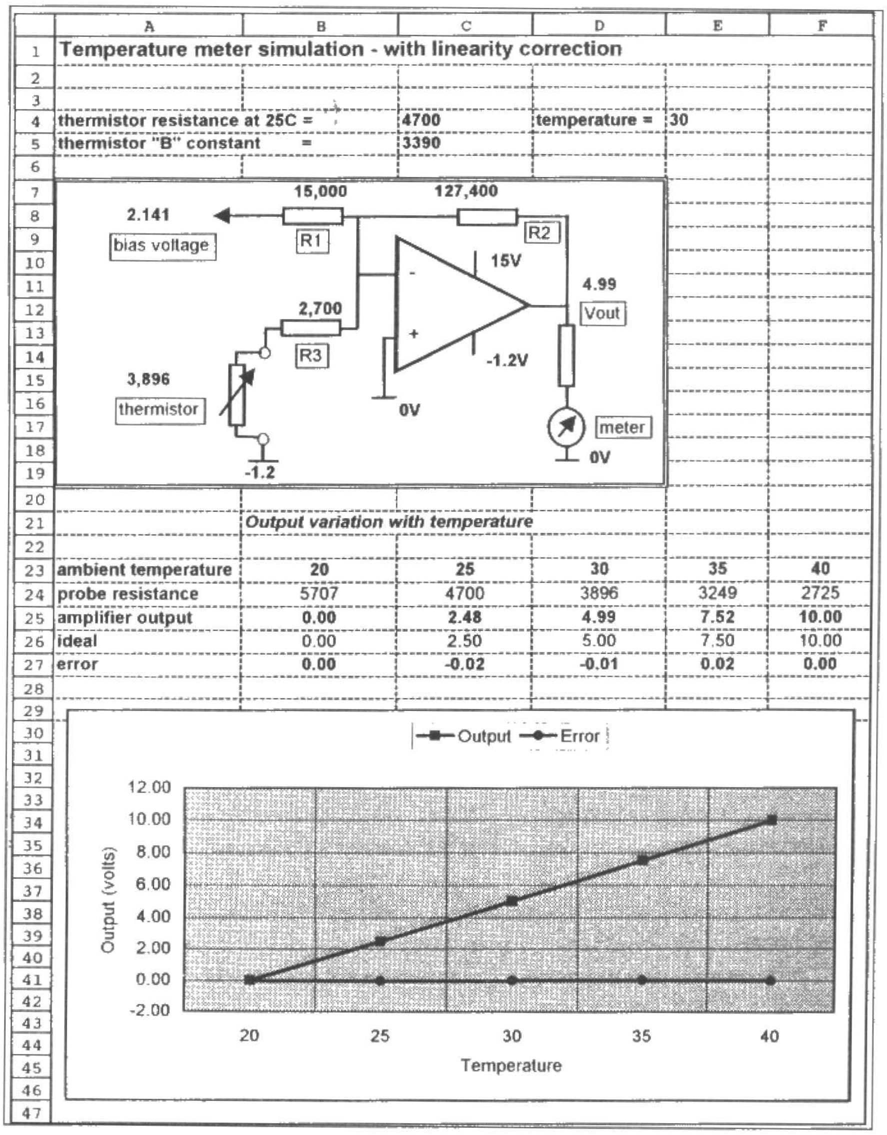
Careful use of rulers and guidelines was required when laying out the tracks. This was tedious but not as bad as I anticipated. The secret lies in doing a few careful pad designs initially, then copying these to build up more complex component pads.

If you don't have a desktop publishing package, you may be able to manage with a drawing package or even the drawing tools provided in a good word processor. Work with a high magnification to reduce errors. Tracks can be drawn directly by setting up a suitable line width. It's a good idea to save many file copies regularly under different names. That way you can recover the situation when you make the inevitable fatal mistake.

Of course there is no output from this system other than a print of the layout so how can this be turned into a printed circuit? I printed the final layout onto transparency film using a laser printer. The film can be used to "contact print" the circuit layout onto photographically sensitised printed circuit board (available from Maplins and other suppliers) if you have the necessary equipment. If you don't, then people who can make up a one-off board or small run can often be found in the classified ads section of ETI.

A final thought

When you next have a problem it is worth looking at whatever facilities you already have. The answer may lie under your nose and it may even be more fun than taking the obvious approach.



	A	B	C	D	E	F
1	**Temperature meter simulation - with linearity correction**					
4	thermistor resistance at 25C =		4700	temperature =	30	
5	thermistor "B" constant =		3390			
21		*Output variation with temperature*				
23	ambient temperature	20	25	30	35	40
24	probe resistance	5707	4700	3896	3249	2725
25	amplifier output	0.00	2.48	4.99	7.52	10.00
26	ideal	0.00	2.50	5.00	7.50	10.00
27	error	0.00	-0.02	-0.01	0.02	0.00

Figure 4: the much-improved linearity after trial and error changes to R3

ETI PCB Service

ETI can supply printed circuit boards for most of our current projects - see the list below for boards available. For recent boards not listed, check the constructional article for an alternative supplier.

Please use this order form or a copy of it. Check that all relevant information is filled in, including the Unit Order Code, and that you have signed the form if sending a credit card number. Overseas customers please add postage appropriate to the number of units you are ordering. Make cheques/POs/money orders, in £ sterling only, payable to Nexus Special Interest Limited. Please allow 28 days for delivery. Access/Visa orders may be made on 01442 266551 (ask for Readers Services).

Only boards listed here are available from our PCB Service. For past issues of magazines, or binders, please see page 74 or contact Readers Services for information.

Name and issue of project	Unit code	Price
ETI PCB Service Issue 11 1998		
Loop Alarm	E/1198/1	£5.09
Ricky Sound (Music Lovers)	E/1198/2	£5.09
ETI PCB Service Issue 10 1998		
Ionisation Chamber	E/1098/1	£5.09
Ionisation Chamber (SMD)	E/1098/2	£5.09
PIC Development Board: see also issue 6	E/698/1	below.
ETI PCB Service Issue 9 1998		
Q Meter	E/998/2	£5.09
Bath Duck	E/998/3	£5.09
ETI PCB Service Issue 8 1998		
PIC Electronics Security Switch	E/898/1	£5.09
PIC Multiplexed LED Display	E/898/2	£5.09
PIC Non-multiplexed LED Display	E/898/3	£5.09
Easy Parker	E/898/4	£6.77
Tiny Traffic Lights	E/898/5	£5.09
Q Meter	E/898/6	£5.09
Bath Duck	E/898/7	£5.50
ETI Issue 7 1998		
PIC 16C74 Development Board	E/798/1	£5.09
Surface Mount Diagnostic Interface	E/798/2	£5.09
Surface Mount Logic Probe	E/798/3	£5.09
Mains Monitor	E/798/4	£12.33
Aquaprobe	E/798/5	£5.50
ETI Issue 6 1998		
PIC Development Board	E/698/1	£5.50
Signal Generator	E/698/2	£8.99
Headlight Delay Unit	E/698/3	£5.50
6-Interval Games Timer	E/698/4	£5.09
ETI Issue 5 1998		
UHF Transmitter (DS)	E/598/1	£5.07
UHF Transmitter Encoder	E/598/2	£5.09
UHF Receiver Front End (DS)	E/598/3	£5.07
UHF Receiver IF stage (DS)	E/598/4	£5.07
Fridge Thermometer	E/598/5	£5.50
AVR Controller	E/598/6	£5.50
27C16 Eprom Programmer	E/598/7	£7.87
Guardian Light	E/598/9	£6.22
ETI Issue 4 1998		
LED Voltmeter	E/498/1	£5.64
BB Ranger Control Board	E/498/2	£6.22
BB Ranger Score Board	E/498/3	£22.89
Line-Up Oscillator with Glitch	E/498/4	£8.99
Tic Tac Toe	E/498/5	£8.44
ETI Issue 3 1998		
Medium Wave Loop	E/398/1	£5.64
AA Cell Eliminator	E/398/2	£7.32
PIC Based Double Bass Tuner	E/398/3	£5.64
5 Range Capacitor Meter	E/398/4	£6.77
MIDI Drum Pads	E/398/5	£5.64
ETI Issue 2 1998		
Smartcam main board	E/298/1	£5.09
Smartcam opto-sensor board	E/298/2	£5.09
Both smartcam boards	E/298/1&2	£7.00
Switched Mode Internal Power Supply	E/298/5	£7.87
Auto Cupboard Light	E/298/3	£5.64
ETI Issue 1 1998		
Control Centre Desk-Top Unit	E/0198/1	£8.99
Control Centre Main Section	E/0198/2	£7.87
ETI Issue 13 1997		
4-Go Rocket Launcher - main board	E/1397/1	£5.64
4-Go Rocket Launcher - relay board	E/1397/2	£6.22
Mighty Midget	E/1397/3	£9.54

Please supply:

Quantity	Project	Unit Order Code	Price	Total price

Prices are inclusive of post and packing in the UK. Overseas Post and Packing (if applicable): Add £1 per unit

Name ....

....

Address ....

....

....

I enclose payment of £ .... (cheque/PO/money order in £ Sterling only) to:

PCB Service, READERS SERVICES DEPARTMENT, Nexus Special Interests Ltd.,
Nexus House, Azalea Drive, Swanley, Kent BR8 8HU

☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐

Signature: ....

Card expiry date: ....

ETI Issue 12 1997

PC Phonecard Reader: ITT Cannon only	**E/1297/1**	**£6.22**
Minute Minder	**E/1297/2**	**£13.98**
Medium Wave Receiver - RF board	**E/1297/3**	**£11.76**
Medium Wave Receiver - Tuning board	**E/1297/4**	**£5.09**
Medium Wave Receiver - Audio board	**E/1297/5**	**£5.09**
Medium Wave Receiver - PSU board	**E/1297/6**	**£6.77**

ETI Issue 11 1997

Total Harmonic Distortion Meter	**E/1197/1**	**£13.43**
Alphanumeric Morse Touchkey	**E/1197/2**	**£5.09**

ETI Issue 10 1997

The IQ Tester	**E/1097/1**	**£5.64**
Fake Flasher	**E/1097/2**	**£5.09**
DC Motors (Part 2)	**E/1097/3**	**£6.77**
Valve Tester - Main Board	**E/1097/4**	**£21.22**
Valve Tester - Socket Board	**E/1097/5**	**£5.09**
Valve Tester - Heater Regulator	**E/1097/6**	**£5.09**
All three Valve Tester boards	**E/1097/4/5/6**	**£30.30**
The IQ Tester (previously E/897/2	**E/1097/7**	**£5.64**

ETI Issue 9 1997

Eprom Emulator	**E/997/1**	**£16.49**
The Power Supply	**E/997/2**	**£5.09**
Electronic Door Chimes	**E/997/3**	**£5.09**
Digital Power Supply	**E/997/4**	**£10.11**

ETI Issue 8 1997

The Brake Light Tester	**E/897/1**	**£5.09**
DC Motors (3 experimental boards)		
DC Motors: The first Control Unit	**E/897/3**	**£5.09**
DC Motors: The 4046 Circuit	**E/897/4**	**£5.09**
DC Motors: The Crystal Drive Circuit	**E/897/5**	**£5.09**
All three DC Motors boards	**E/897/3/4/5**	**£11.50**

ETI Issue 7 1997

Eprommer: main board (double sided)	**E797/1**	**£13.32**
Eprommer: PSU board	**E797/2**	**£5.64**
Eprommer: personality modules (double sided):		**E797/3**

Any ONE module board: £5.09; two modules: £7.90; three modules: £11.85; four modules; £15.80: five modules: £19.75; All six modules: £23.70

Please specify which Eprom modules you require. Modules are for 2716, 2732, 2764, 27128, 27256 or 27512. One order code/overseas postal charge applies whether a selection or all six personality module boards are ordered.

Are Your Lights On?	**E/797/4**	**£5.09**
Peak Reading VU Meter	**E/797/5**	**£5.09**

Terms of trade

Terms strictly payment with order. We cannot supply credit orders, but will supply a proforma invoice if requested. Proforma orders will not be processed until payment is received. All boards are manufactured from the foils that appear in the ETI Foils Pages for the appropriate issue. Please check that our foils are suitable for the component packages you intend to use before ordering as we cannot supply modified boards or replace boards that have been modified or soldered. Boards are only supplied in the listed units. Sorry, we cannot break units. Prices and stock may be altered without prior notice. Prices and stock listed in this issue supersede prices and stock appearing in any previous issue. ETI, Nexus Special Interests and their representatives shall not be liable for any loss or damage suffered howsoever arising out of or in connection with the supply of printed circuit boards or other goods or services by ETI, Nexus Special Interests or their representatives other than to supply goods or services offered or refund the purchaser any money paid in respect of goods not supplied.

The International Model Show and The Model Engineer Exhibition 1997/1998

was a record breaker, attracting over 50,000 visitors.

Following this outstanding success

The International Model Show and The Model Engineer Exhibition 1998/1999

(29th December 1998 - 3rd January 1999)

- the last to be held in the Grand Hall, Olympia -

promises to be an even more spectacular event. Visitors at last year's show were unanimous in praising the exhibition for providing a great day out for all the family, and the Show's clear and easy-to-follow layout also attracted positive comment.

Manufacturers and suppliers who had stands at the show reported a busy exhibition, with sales well up on the previous year, and in general a much improved event.

Between now and the Show's opening, Nexus organisers will be striving to make further improvements to its layout and format and are working hard to ensure that the 1998/1999 exhibition will be even more attractive to traders who exhibit, and even more memorable for visitors.

Nexus publications such as Radio and Control Models and Electronics, Model Boats, Model Engineer, Model Engineer Workshop, Scale Models, Radio Modeller, Aero Modeller and many more will be exhibiting and introducing live displays to the public.

To book your company a stand at the exhibition, contact John Furlong, Sales Manager at Nexus Media. Tel: 01322 660070 Fax: 01322 667633.

Yes, I would like to receive further information about the The International Model Show and The Model Engineer Exhibition 1997/1998. ETI reader:

Name ....

Address ....

....

Please send for the attention of The Editor, ETI, Nexus House, Azalea Drive, Swanley BR8 8HU.

Versatile Loop Alarm

Terry Balbirnie

This general-purpose alarm uses the well-tried "broken loop" principle. This type of alarm is virtually immune from false triggering and inexpensive to construct.

It is also very versatile - it can even be used to protect several items around the house and garden at the same time.

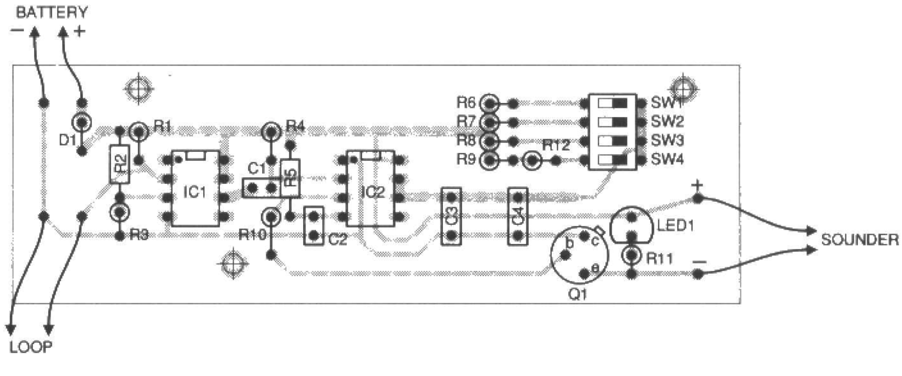


Figure 2: the component layout of the Loop Alarm

A bit loopy

The Loop Alarm was originally developed to protect a caravan against theft and entry when left in storage. It could just as easily be used for bicycles, boats and camping equipment, not to mention garden tools such as lawn mowers and chainsaws.

Overview

The alarm comprises one unit in a metal box containing the circuit panel, battery pack and a loud "yelping" sounder. (But you could also site the sounder remotely).

In use, two sockets on the side of the unit are interconnected by piece of flexible wire with a plug on each end. This is passed through any parts of the item(s) to be protected that it cannot be removed from without first unplugging it. For example, it could be run between the holes in a car or trailer wheel, the spokes of a bicycle wheel or the handle of a lawnmower (as long as it is not the type that unscrews quickly with a wingnut!) Before the item can be removed, the wire must be cut or unplugged, and this will trigger the alarm.

Switches with normally closed contacts could also be included in the loop - for example, magnetically operated reed switches or micro-switches. These could be used to detect when doors or windows are opened. Some readers may wish to use this kind of switch as an anti-tamper measure so that the alarm will be triggered if anyone attempts to move the box, however, this should not normally be necessary if the unit is placed out of reach.

The loop wire may be of any reasonable length so that it can be used to protect items over a wide area. Line connectors can be included at intervals along the wire so that items can be added or removed easily. You could make up several loops of different lengths so that you can select one to suit your current application. Please note, however, that the unit and any connectors must be kept dry. Any plugs, sockets and switches used outdoors must be of waterproof types or be suitably protected. Any corrosion could result in poor contact which the circuit would interpret as a break in the loop.

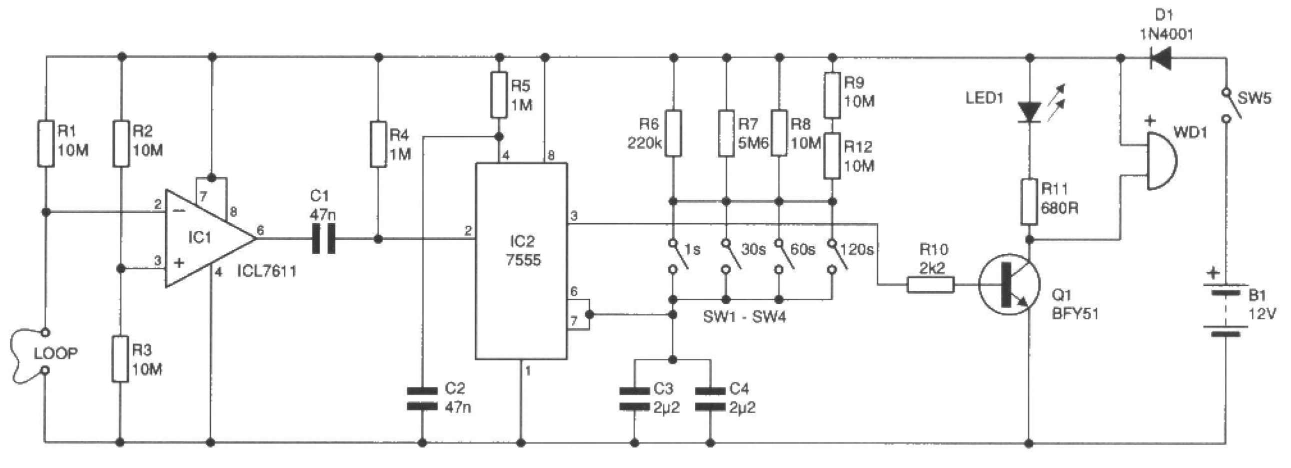
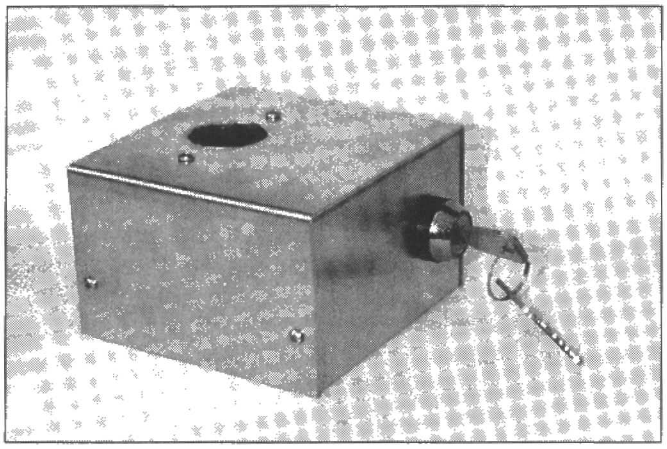


Figure 1: the circuit of the Loop Alarm



Once triggered, the alarm will sound for a preset time from about one second (for testing purposes) up to nearly two minutes, and the sound will continue even if the loop is re-made. The only way to silence it prior to time-out is to cancel it using the key-operated switch that the owner will also use before removing an item.

The circuit requires a standby current of 100 to 150uA. The specified battery pack of eight AA alkaline cells could maintain this for two years or more. However, the alarm will need to sound occasionally (if only for testing purposes) so the batteries are best replaced every year, more frequently if the alarm has sounded for long periods.

It is important to remember that no alarm is completely foolproof. To prevent the theft of valuable items, more than one means of protection should be used. For example, a caravan could be fitted with this alarm and a good-quality wheel clamp. You should also check their requirements with your insurance company, as this may affect a claim if you have one.

How it works

Figure 1 shows circuit. If the key-operated switch SW5 is in the on position, battery pack B1 provides its 12V supply through diode D1. The diode gives reverse-polarity protection.

While the loop (on the left of **figure 1**) is unbroken, the non-inverting input (pin 3) of micropower op-amp IC1 is maintained at half the supply voltage (nominally 6V) by the potential divider, R2 and R3. The inverting input is kept low by the loop. The voltage at the non-inverting input is therefore greater than that at the inverting one, so the op-amp is on and its output, pin 6, is high.

If the loop is broken, R1 causes the inverting input to go high and exceed the voltage at the non-inverting one. The op-amp switches off sending pin 6 low. A low pulse will be sent to IC2 trigger input (pin 2) via C1.

Note that resistors R1, R2 and R3 have a very high value to minimise the continuous current flowing through them. IC1 has been set for minimum current requirement by making pin 8 (the program pin) high.

What's the time?

IC2 is a timer ic configured as a monostable, triggered by the low pulse from IC1. Its output pin 3 goes high for a given time and then reverts to low. The time is chosen from one of four preset values via one of four dip switches (SW1 to SW4). Each switches into the circuit a resistor (R6 to R9), which with C3 fixes the monostable time period. The lowest resistor (R6) in the circuit gives about one second. This is handy for testing and setting-up. R7 gives about 30 seconds, R8 gives about 50 seconds and R9 about 100 seconds. Raising the value of either C3 or the appropriate timing resistor will increase these operating periods.

While IC2 output is high, current flows to the base of transistor Q1 via R10 and turns it on. Collector current then operates the audible warning device (piezo siren) WD1, and also LED1, which is current-limited by R11 to a suitable working value. The LED will be useful for testing the circuit before connecting the sounder.

C2 maintains IC2 reset input (pin 4) low for a short time after switching on so that it will not trigger on power-up. Following that, R5 makes pin 4 high and enables the device. R4 maintains IC2 trigger input in a normally high condition. This prevents any false triggering which could occur without it.

Construction

The Loop Alarm uses a single-sided PCB (**figure 2**). Begin by drilling the three mounting holes. Solder the ic sockets, the piece of screw terminal block TB1 and the dip switches in position.

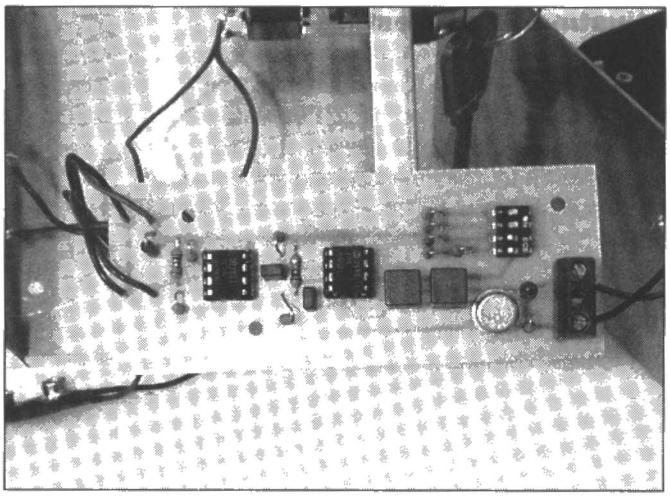
Follow with all resistors and capacitors. In the prototype, R9 and R12 are two 10M units because this is the highest value easily available. You could use a single 22M resistor in the place of R9 and short-circuit R12 with a wire link. C3 in the prototype is two 2.2uF capacitors in parallel (C3 and C4), but a single 4.7uF capacitor could be used instead (the C4 position would be left unconnected). I have avoided electrolytic capacitors in this circuit to improve reliability.

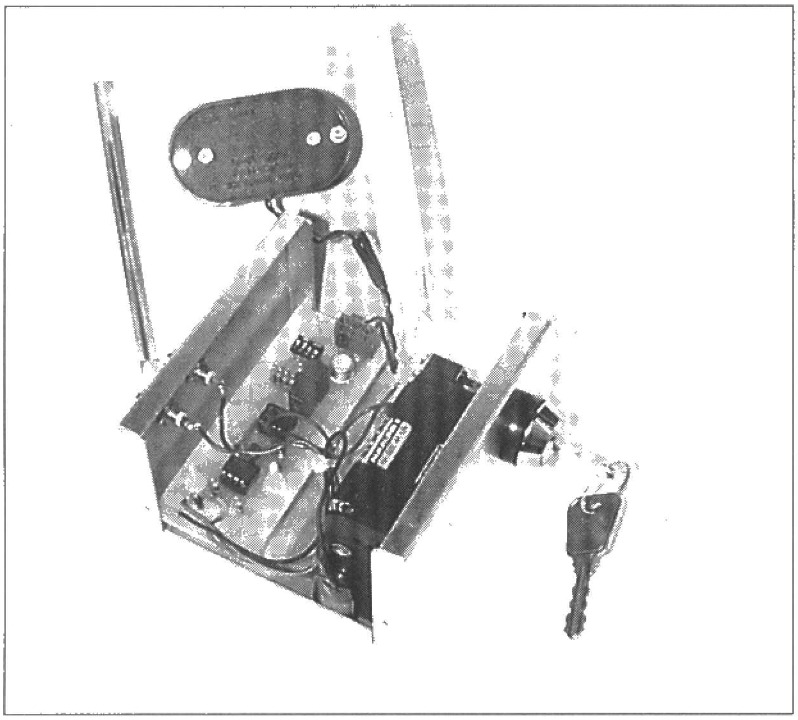
Solder D1 and the LED in position observing their polarity. Finish with transistor Q1 taking care over orientation because it is "upside down" compared with usual practice - that is, the emitter is at the top. The tag on the transistor body is closest to the emitter. Solder 10cm pieces of stranded connecting wire to the points labelled "loop". Solder the negative wire of the PP3-type battery snap to the "battery -" point, and a 10cm piece of stranded wire to the "battery +" one.

Insider dealing

Check the inside of the box to work out the best layout for the components, and whether the sounder is to be mounted inside the box (as in the prototype) or externally. At this point, it would also be a good idea to decide how you want to secure the unit, so that any fixing holes needed can be drilled in the back. It might also be a good idea to connect the sounder direct to the battery pack to check that it will be loud enough for your applications.

In the prototype, the battery holder was attached to the base next to the circuit panel (see photograph). The switch and





loop sockets were mounted on the side, with the sounder on the lid section. All this will depend to some extent on the box being used.

Mark the positions of the PCB and other mounting holes, drill these and attach them. When mounting the PCB, use short plastic stand-off insulators on the bolt shanks - this will ensure that all copper tracks on the underside remain clear of the bottom of the box. Make a bracket to hold the battery holder but do not fix it in place yet.

Connect the centre (pin) connection of each phono socket to the "loop" wires leading from the PCB. If the key-operated switch is of the SPST type, there will be only two tags so connecting it will be straightforward. If it has a more complex contact pattern, use a multi-tester set to a low resistance range to identify the normally open contacts if necessary. Connect one tag to the positive battery snap wire and the other to the "battery +" wire leading from the PCB. Do not connect the sounder wires yet (so that it will not operate during testing).

Insert IC1 and IC2 into their sockets the right way round. These are CMOS components, so touch something earthed (such as a water tap) before inserting them to protect them from static. Set dip switch SW1 ON and the other three OFF (to give the shortest timing).

Adjustment and testing

Set the key-operated switch OFF. Insert eight alkaline AA cells in the battery holder and connect it. Secure it with the bracket ensuring there are no short-circuits with the case. Insulate it using a piece of cardboard if necessary. Cut a piece of wire of suitable length to make the loop and solder the pin connection of a phono plug to each end. Extra-flexible wire is best for the job. Do not use single-strand wire which is likely to break in service (and trigger the alarm). Insert the plugs into the sockets on the unit.

Switch on and check that the LED does not light. Remove a plug to break the loop - the LED should operate and go off again about one second later. Check the other timings by operating dip switches SW2 to SW4 in turn. Note that only one switch should be on at a time. Test the sounder on the shortest timing by connecting its wires (extended as necessary) to TB1, in the right polarity or it will not work. Use one of the dip switches to set the required time-out period, and set the key-operated switch to OFF.

Secure the unit in position. It will be best if it is made as difficult as possible for a potential thief to reach. If you decide to mount the sounder remotely, the wires should be routed carefully to make them difficult (and better still, difficult to see). Wherever the main unit is placed, it must not be possible for rain spray to reach it. When you are satisfied with the arrangement, fit the lid using anti-tamper screws if this is thought necessary. Carry out a test under real conditions. If possible, display a professional-looking alarm sticker on the property.

Choice of sounder

The piezo sounder combined loudness, low current requirement and small size. It should draw no more than 300mA from the supply. The one used in the prototype required only 150mA, but a larger one could be used if a larger box was used, or the sounder was mounted externally.

Every few weeks, the alarm should be triggered for a few seconds to make sure everything is working. If the sounder lacks power, replace the batteries.

PARTS LIST *for the Loop Alarm*

Resistors

R1, R2, R3, R8,R9, R12	**10M**
R4, R5	**1M**
R6	**220k**
R7	**5M6**
R10	**2k2**
R11	**680R**

Capacitors

C1, C2	**47n metallised polyester (2.5mm pin spacing)**
C3, C4	**2.2u metallised polyester (5mm pin spacing)**

Semiconductors

IC1	**ICL7611**
IC2	**ICM7555IPA**
Q1	**BFY51**
LED1	**3-mm red LED**

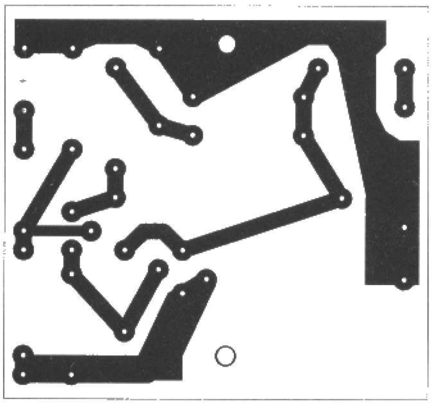
Miscellaneous

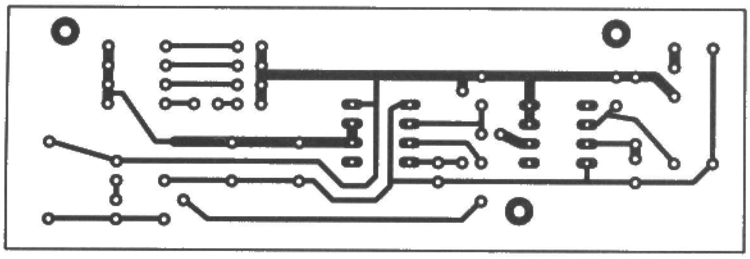
SW1	**Key-operated switch**
WD1	**Piezo sounder, 12V dc operation at 300mA maximum - see text**
TB1	**2-way screw terminal block, 10mm pin spacing**

PCB; 8 x AA size alkaline cells and holder; PP3 battery connector; 2 x single-hole mounting phono sockets; 2 x 8-pin dil sockets; aluminium box for project.

All components are available from Maplin. The sounder used in the prototype was order code JK42V.

FOILS FOR THIS ISSUE


Ricky Sound (Music Lovers)


Loop Alarm

PRACTICALLY SPEAKING

By Terry Balbirnie

Last month we saw how the operating range of a potentiometer may be reduced by connecting resistors in series with its track. This time, we shall look at how the required value of a variable resistor may be fabricated using one of a higher value.

Making up

Suppose the designer of a circuit specifies a value of 47k for a variable resistor (to make things easier we shall regard this as 50k). A potentiometer would then be used as shown in **figure 1** with one of its track tags left unconnected. By rotating the sliding contact (the wiper), the resistance appearing between points A and B may be varied from zero to 50k as required.

Suppose you want to build such a circuit but when you look in your box of components, you find that you only have a 100k potentiometer. You could simply substitute the 100k potentiometer and hope for the best. In many cases this will be entirely satisfactory but, unless you have a pretty good knowledge of electronics, you may find that the circuit does not work properly or at all. If, for example, the variable resistor was used in a timing circuit, the maximum operating period would be "out" by a factor of two.

There is a better way to tackle this situation, and this is to connect a fixed resistor with a value of 100k across the potentiometer track connections as shown in **figure 2a**. This is how it works. When the sliding contact is at the bottom of the track, there will obviously be a resistance of zero ohms between the points A and B (**figure 2b**). When the sliding contact is at the top (**figure 2c**), the whole arrangement is equivalent to two 100k fixed resistors connected in parallel giving 50k as required?

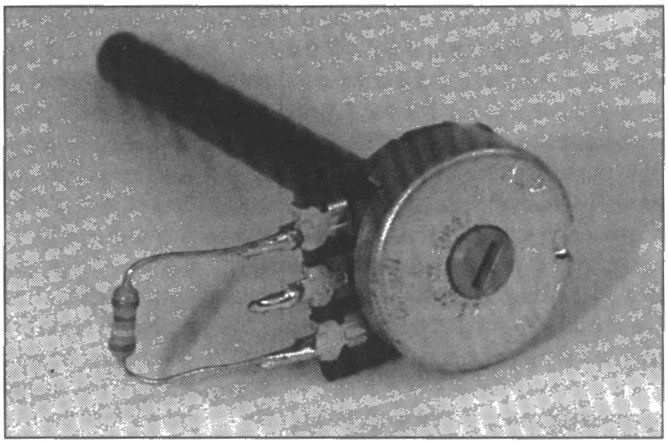


Figure 1

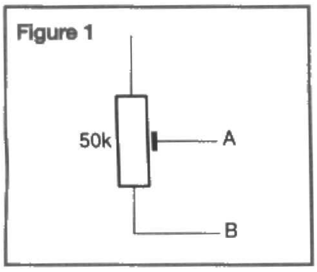


Figure 2a

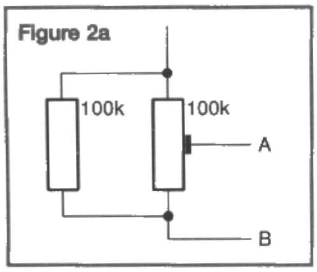


Figure 2b

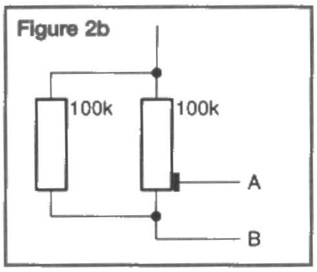


Figure 2c

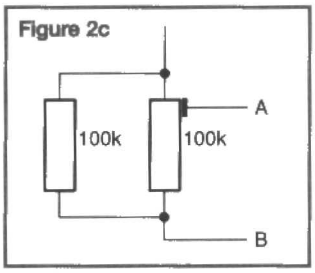
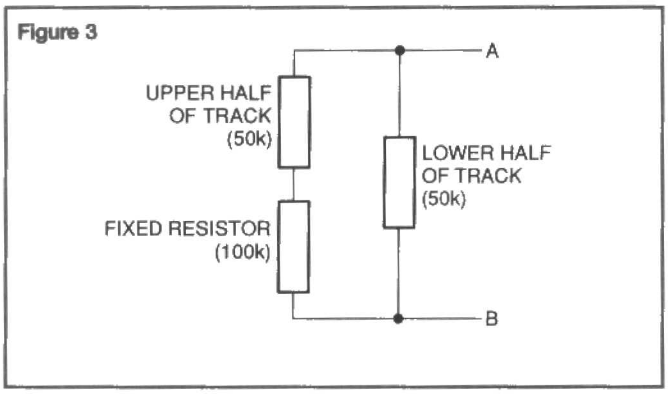


Figure 3



Not what it seems

However, if we look more closely we find that this arrangement has a certain twist to it. We can see this most easily if we consider the sliding contact to be at the centre of the track. If the potentiometer was a single 50k component (assuming it was of the linear kind) we would expect the resistance between points A and B to be 25k.

Look at **figure 3**, which shows the equivalent circuit. Here, the lower half of the potentiometer track (50k) appears between points A and B. However, the top half of the track, connected in series with the fixed resistor also appear between the points A and B (that is, 150k). The combined effect is therefore one of a 150k resistor connected in parallel with a 50k one. Using the formula for the result of connecting resistors in parallel discussed in a previous part of this series (and working in kilohms instead of ohms):

$= 1/50 + 1/150$

$= 0.02 + 0.0067$

$= 0.0267$

so $R = 1/0.0267$k

$= 37.4$kilohms.

(remember, this is the resistance appearing between points A and B and with the spindle "half way"). If we had used a single 50k linear potentiometer, we would have expected the result to be 25 kilohms.

It seems that the characteristics of the equivalent variable resistor are no longer linear (where equal degrees of rotation of the sliding contact provide equal changes in resistance). It now seems that there is a larger variation in the lower half of the track than the upper one. However, there are few cases where this would matter in a practical circuit.

Next month we shall look at some aspects of practical circuit-building.

Round the Corner

Energy for the Future

The main story in this issue features a solar-powered catamaran. Everyone agrees that solar power will be very necessary in the future, but who is sticking their neck out to test it in the field? This is a good example of a way to test how practical it is to put solar power, the greatest source of renewable energy, to use. Another example is an architect in Oxford who has designed (and lives in) an energy efficient house, with all the electricity provided by solar panels. There is even enough to charge the batteries in a small car converted to run on electricity.

It is important for everyone that experimenters carry out projects like this, both to show what can be done, and to assess the further limits of the approach. However, these two examples share one necessity: a very significant amount of energy storage must be available in rechargeable batteries. For tens of years we have been waiting for a breakthrough in rechargeable battery technology, so that, for example, we can store enough energy to power an electric car for 300 miles in something not too much heavier or larger than a tank of fuel.

But this has not arrived. There have been incremental improvements in battery technology which add up to a significant amount over a decade, but even more is needed to make electric transport easy to run. When economic energy storage with the required energy-to-bulk ratios becomes available, we will see big steps forward in the use of solar power.

However, if this does not happen soon, my guess is that we will have to begin investigating the supply of electricity from solar power satellites, which will generate microwaves from sunlight, and then beam the microwaves to rectenna farms on the earth's surface. This will provide electricity during the night, or when there is heavy cloud cover, so will not require so much storage. The energy density in space is greater than the maximum of about 1kW per square meter at the equator on a clear day arriving on Earth.

In Britain we receive more like 500W/square metre on a sunny day, and less if it is cloudy. In round figures, for affordable systems, conversion efficiency of 10 percent is realistic, so the peak power output of a 1 square metre of solar panel would be about 50W. This is not available all day every day, so a 1 square metre of solar panel might give you 10W average power over the year.

This figure should increase in the next few years. If it does - watch houses with a large area of south facing roof increase in value!

Next Month

Volume 27 No 12 of *Electronics Today International* will be in your newsagents on 6th November 1998. Douglas Clarkeson dives into the difficult world of electronic filters and comes up with some straightforward, software-aided approaches to filter design ... Martin Smith addresses the basic maths ... Pei An's temperature and humidity logger operates from the Centronics port of a PC and stores data for future analysis, as well as displaying the measurements on LCD readouts ... Store your beer at absolutely the right temperature with the Beerstat temperature control ... and much more.

Contents are in preparation but are subject to space and availability.

Make sure of your copy of

ELECTRONICS TODAY INTERNATIONAL

Complete this coupon and hand it to your newsagent

Please order me a copy of *ETI* every month

Reserve me a copy ☐ **Deliver it to my home** ☐

Name: ________________________________

Address: ________________________________

____

________________________________ **Postcode** ______________

ETI is distributed to newsagents wholesalers by Comag Magazines Marketing, Tavistock Road, West Drayton, Middlesex, UB7 7QE.
Tel: 01895 444055 Fax: 01895 433602.

MAGAZINE MONTH

Look for this symbol which guarantees a good order or delivery service

ETI
ELECTRONICS TODAY INTERNATIONAL

Published by
Nexus Special Interests Limited
Nexus House, Azalea Drive,
Swanley, Kent BR8 8HU
Tel: 01322 660070 Fax: 01322 615636

Sorry, we cannot answer queries about projects or other technical queries on the phone. Our administration assistant Jenny can often help with other queries about this issue

Our web is http://www.aaelectron.co.uk/eti/
Email address: eti@aaelectron.co.uk.
Please note! This is currently only an editorial web site.
Please send enquiries about subscriptions, advertising etc. to Nexus Special Interests' postal address above.

EDITORIAL

Editor
Helen Armstrong

Administration Assistant
Jenny Etheridge

Consultant
Andrew Armstrong

PRODUCTION

Designer
Paul Forster

Technical Illustrator
John Puczynski

Production Executive
Marie Quilter

Printed By
Wiltshire Ltd., Bristol

Origination by
Atelier, St. Austell

SALES

Midland and Southern Area Sales
Mark Colyer
01322 660070

Northern Area Sales
Denise Barrow
0161 776 4460

Newstrade Sales Manager
David Pagendam

MANAGEMENT

Group Managing Director
Tony DeBell

Divisional Managing Editor
Dawn Frosdick-Hopley

Divisional Sales Manager
Roy Kemp

Circulation Manager
William Pearson

Group Marketing Manager
Aileen O'Connor

SUBSCRIPTIONS

UK:Orders 01858 435344
Enquiries 01858 435322
USA: Wise Owl Worldwide Publications, 4314 West 238th Street, Torrance, CA90505-4509, USA. For VISA/Mastercard orders phone: (310) 375 6258. Fax: (310) 375 0548. Pacific Time: 9am - 9pm weekdays 10am - 6pm weekends. Visa/MC/Discover accepted.

READERS SERVICES
Back issues(last 12 months) £3.20 per issue if available. Binders for ETI: £7.50 each including UK post and packing. Overseas please add £1.50. Cheques to Nexus Special Interest at Nexus House, or phone VISA/Mastercard orders to Readers Services Department 01322 660070

FOR ENTHUSIASTS BY ENTHUSIASTS
NEXUS

© Nexus Special Interests Limited 1998
All rights reserved

ISSN 0142-7229

The Publisher's written consent must be obtained before any part of this publication may be reproduced in any form whatsoever, including photocopiers, and information retrieval systems. All reasonable care is taken in preparation of magazine contents, but the publishers, editors and their agents cannot be held legally responsible for loss howsoever arising from errors or other published material.

electronics
& beyond
Sept 98 feb 99
17,000 NEW products
in our semiconductor supplement
Price reductions on over 2,000 products
visit our Web Site
http://www.maplin.co.uk
Companion CD
catalogue

MAPLIN
ELECTRONICS

Order your catalogue now on 01702 554000 or visit and collect from one of our 48 stores nationwide. You can also purchase your catalogue from your local Maplin store, WH Smith and John Menzies.

CATALOGUE
- Over 1,000 new products
- Includes over £50 worth of discount vouchers
- Order code CA18

DOUBLE CD
- Includes FREE datasheet CD-Rom
- FREE McAfee anti-virus software
- FREE 30 day Demon Internet trial
- Order code CQ02

THE NEW CATALOGUE OUT NOW

£3.99

£1.95

the key to better selection and service

Telephone 01702 554000 with your enquiry

The catalogue costs just £3.99 plus p+p* and the CD Rom is available at just £1.95 plus p+p* including free datasheet CD Rom.
*(Add 50p for P&P). Orders outside the UK please send £8.99 or 21 IRCs for Airmail in Europe or surface mail outside Europe. Send £16.04 or 37 IRCs for Airmail outside Europe to: Maplin Electronics, PO Box 777, Rayleigh, Essex, England, SS6 8LU. Prices include VAT and are subject to change. All items subject to availability. E+OE. **WHEN ORDERING PLEASE QUOTE PRIORITY CODE MA112**